AN INVESTIGATION OF THE EFFECTS OF TARGET SIZE, TARGET LOCATION CERTAINTY, DISTRACTING IMAGES, AND INFORMATION CONTENT ON CHOICE-REACTION TIME, WITH PARTICULAR ATTENTION TO APPLICATION IN PRE-DETERMINED MOTION-TIME SYSTEMS

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SUMMARY

There are many industrial tasks which involve making a decision between alternatives based on a stimulus, frequently visual. Most predetermined motion-time systems do not account explicitly for the mental processing time required. In an effort to establish a framework for the estimation of this time, several variables which affect choice-reaction time were investigated.

Investigation of the pertinent literature allowed the development of a comprehensive list of factors which affect choice-reaction time. The literature also indicated that the variables which affect that time may be segregated into two independent sets, those which affect the information-processing time necessary to make a decision. A hypothesis was formulated: that choice-reaction time may be estimated by adding a "basic detection time", established from the effects of certain variables, and information-processing time, established by the variables associated with information content.

Variables chosen for investigation were target size, target location certainty, distracting visual images, and average information content in the stimulus. In the experiment, six subjects responded to visual stimuli varying over two levels of size, location certainty, and distracting images, and three levels of information content. Response times were averaged across subjects for each combination of variable levels and plotted against information content. Linear regression models were then fitted to determine slope and intercept values for each

combination of variable levels. Fixed-effects analysis of variance models were applied to the resulting slope and intercept values to evaluate the basic experimental hypothesis.

Results indicated that target size, location certainty, and particularly, distracting images definitely affect (and so may be used to establish) "basic detection time". It was also indicated that information-processing time, established by information content, was not affected by the other variables. However, the power of the analysis of variance did not allow this to be a definite conclusion.

CHAPTER I

INTRODUCTION

Background

The various predetermined motion-time systems currently available account for all industrially significant physical motions; with few exceptions, however, they do not account for the time taken for simple decision-making, such as deciding to accept or reject an item going through an industrial inspection. This mental processing time can be a significant portion of the total time for an industrial task and should be covered by predetermined motion-time systems (PMTS). There exists, then, a requirement for a framework to incorporate decision time into predetermined motion-time systems. The general objective of this study is to delineate the variables which contribute to the time involved in decision-making and to investigate a procedure by which the effects of certain of those variables can be combined in order to estimate that time.

As an initial step, the following list of factors (variables) which have an effect on decision time was developed (their effects will be documented in Chapter II):

Target size - the size (expressed as visual angle subtended) of the individual visual image (e.g., an alphanumeric character) which will give rise to a decision.

Target location certainty - the degree to which the decision aspect, or target, will appear in a fixed location throughout repeated target presentations and decisions.

Size of the visual field to be searched, if the location of the target is uncertain.

Illumination - the brightness level in the target area, or the entire field if location is uncertain.

Contrast - the ratio of brightness between the target and its background.

Color contrast - the difference in hue between the target and its background, maximum color contrast existing for opposing hues on a color wheel (complimentary colors).

Target "difficulty" - the identifiability of a target arising from its shape (compact, "blocky" targets having higher difficulty than generally linear or uniquely-shaped targets).

Clutter - the presence and density of distracting images, other than the target, in the field.

Target movement - angular velocity of the target across the visual field.

Temporal certainty - the degree to which the target will be presented when expected by the decision-maker.

Factors relating to information content:

- the number and probabilities of alternative target conditions (stimuli).

- the amount of information reduction in the decision task.

- the fineness of discrimination required by the task. (See Chapter II for a detailed discussion of these variables.)

Speed and Load Stress - the frequency at which the decision-maker is called on to respond to a stimulus and the number of separate locations where stimuli may be presented.

Age of the decision-maker.

Training - the degree to which the decision-maker has fully learned to correctly associate decisions with target conditions.

Fatigue - mental boredom.

Preview time available - the amount of time that the decision-maker has to observe the target before he is called on to make a decision about it.

Scope

The decision-making considered in this study was solely non-creative decision-making, the type of decision-making performed when choosing between alternatives. Creative decision-making (e.g., "brain-storming" or the decision-making process in complex problem-solving) was not considered. Furthermore, the study was limited to decision-making based on visual inputs only, since tasks involving decision time to which PMTS might be applied usually involve visual discrimination. The relationships developed herein, however, could be extended to include auditory, tactile, or taste discrimination.

Several comments may be made concerning some of the variables listed above, considering the industrial environment in which predetermined motion-time systems are applied. PMTS allow the training factor to be disregarded, as they assume that the operator is fully trained in the task. Operator age is not considered in PMTS, a standard age being assumed. Also, fatigue is not included in PMTS tabulations of other actions, since it is accounted for as an allowance. It might also be pointed out that in many industrial situations, others of the above-listed variables might be controllable, either by workplace design or task design. These variables include illumination, target movement, and speed and load stress.

Specifically, for this study the independent variables under consideration were limited to target size, target location uncertainty and clutter combined as "degree of confusion", and, to establish information content, the number of possible target conditions.

Hypothesis

The literature suggests that the following variables affect only the "simple reaction time", the time necessary to simply detect and identify a stimulus and initiate a response: target size, target location uncertainty, size of the field, target "difficulty", clutter, target movement, and temporal uncertainty. The variables listed earlier that are associated with information content apparently affect only an additional increment of time, beyond simple reaction time, necessary for information processing. The literature is less clear concerning illumination and contrast. These variables are clearly linked to simple reaction time but may also, through an "uncertainty" effect associated with information content, generate an additional time increment in decision-making, at least for low values of illumination or contrast. In general, however, especially where illumination and target contrast can be enhanced by work place design, it seems that mental processing time may be developed by determining a "basic detection time" and adding to it an increment required for information processing. The "basic detection time" would be determined by combining the effects of target size, field size, clutter, etc., and the time required for information processing would be determined from the average information content in the decision task.

The hypothesis to be examined in this study, then, is that the variables affecting choice reaction time in an industrial task can be segregated into two relatively independent sets, one that establishes a basic detection time and another that establishes an additional information processing time increment. This can be illustrated graphically by Figure 1-1. The hypothesis states that the time necessary for an industrial decision task can be estimated by developing a basic detection time ("BDT" on the ordinate in Figure 1-1) from the effects of certain variables and then adding to that an additional increment ("IPT" in Figure 1-1) proportional to the average information content in the decision.

Summary of Methodology

An experiment was devised to determine the effect on reaction time of those variables in order to test the hypothesis stated above. Subjects were presented visual stimuli which could be varied across the independent variables. The subjects were to respond manually based on the condition of the stimuli presented. The data collected were the reaction times under the various stimulus conditions. Response (reaction) times averaged across subjects for all variable combinations were then plotted against input information content and linear regression was applied to develop slope and intercept coefficients for each of the stimuli conditions. The hypothesis of this study was then examined by fitting a fixed-effects analysis of variance (ANOVA) model to these

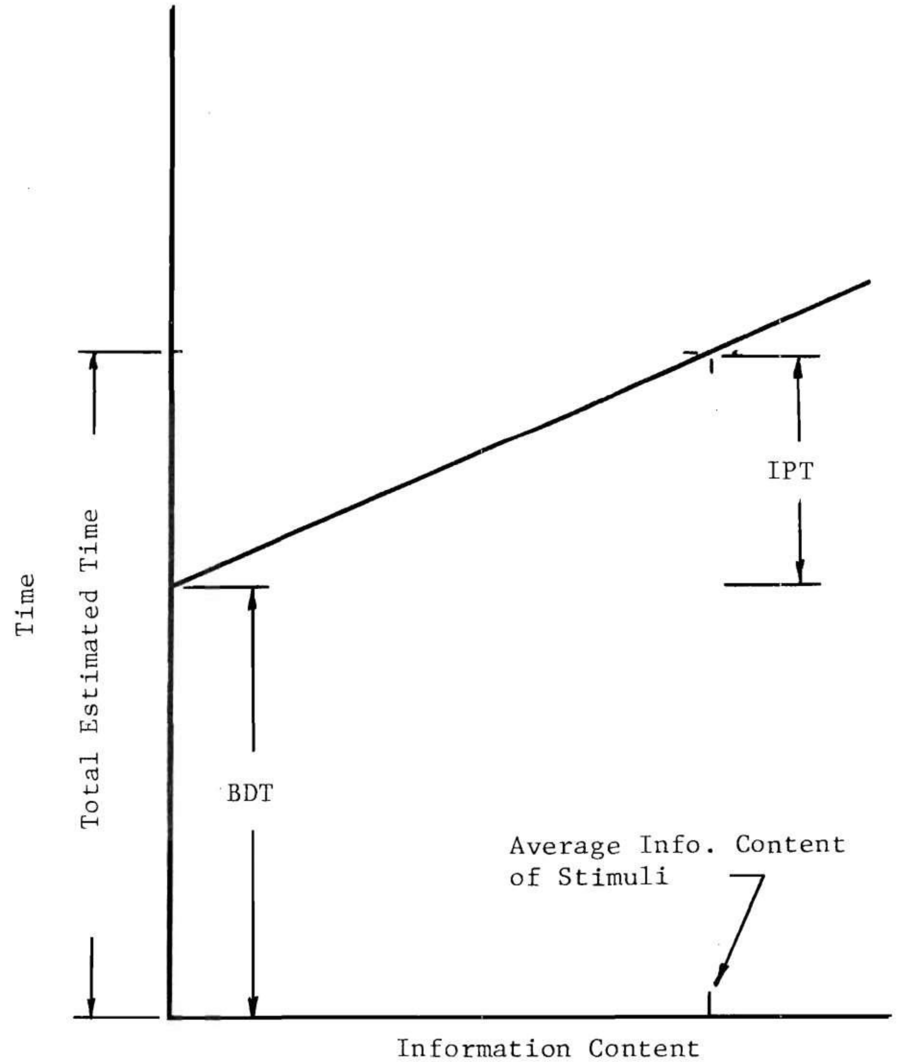

Figure 1-1. The Hypothesis Illustrated.

coefficients. The hypothesis would be supported if ANOVA showed that the intercept values were significantly different for different conditions of target size, clutter, etc. and that the slopes (which are the reciprocal of the information processing rates) could not be shown to be significantly different.

CHAPTER II

LITERATURE REVIEW

General

It has been long recognized that even the simplest decision-making is time-consuming. One of the earliest lists of elemental actions, Frank B. Gilbreth's list of "therbligs", included the element "select" (Maynard: 2-7), which is defined in the Motion Time Analysis system as "the act of making a choice between two or more pieces which are in a known location" (Maynard: 5-6). Most predetermined motion-time systems, however, have disregarded decision time or combined it with motion times, primarily because these systems grew out of analysis of motion pictures, (Maynard: 5-3) which provide for the decomposition of physical motion only. Furthermore, times for mental actions do not lend themselves to inclusion in PMTS because they are difficult to measure. They do not have well-defined starting and ending points that are manifested in some measurable manner, and they have been found to overlap considerably with physical actions, particularly physical actions which are highly practiced and/or simply executed. A major obstacle in research on reaction times and other mental process times has been that of divising experimental procedures which isolate the mental processing time from the time involved in stimuli detection and muscular response while retaining measurable stimuli and response events.

A notable deviation from PMTS which involves physical actions only is the "Work Factor" system developed by J. H. Quick, J. H. Duncan, and J. A. Malcolm. This system is proprietary; although it is explained by the developers in elaborate detail in Work Factor Time Standards, documentation of the system's tabular entries and their derivation is not provided.

The Work Factor system has as a standard element "Mental process"; sub-elements include "identify", "discriminate", "nerve conduct" and "decide" (Maynard: 5-8). The individual times for these sub-elements, as determined by the Work Factor organization have been combined into tables under such actions as "react", "inspect", "compute", etc. (Maynard: 5-88). The actions related to the industrial tasks considered in this study are "react" and "inspect".

"React" in the Work Factor system, consists of receiving external stimuli and preparing to perform the appropriate subsequent physical or mental act (Quick, et al.: 166). Various sensory modalities are allowed as input to "react". Variables affecting react time are operator anticipation and number of alternative responses (Quick, et al.: 182). "Adequate" illumination for the task is assumed. Variables affecting inspect time are the size of the largest "inspection character" and its contrast with its background.

Individual Variable Effects

A great deal of research has been done relating individual variables, such as those listed in Chapter 1, to the time necessary to make a choice and initiate a response and to the reliability of those decisions. Much of that research is reviewed below.

Target Size

The ability to quickly and reliably identify visual targets is obviously related to their size (visual angle subtended). A 1960 study by Steedman and Baker developed the data shown in Figure 2-1. In this study the errors in identifcation followed essentially the same curve when plotted on the appropriate linear scale. This illustrates that the minimum size for reliable and quick identification of specific targets in a cluttered field in good illumination is 12 minutes of visual angle; errors and identification time quickly increase for smaller visual angles. Low contrast and difficult target patterns or shapes aggravate the situation, requiring two or three times the sizes shown above for the same identification times (Steedman and Baker: 58).

The relationship between the size of the target to be detected and the simple reaction time associated with the target-stimulus has been developed for two different situations by Hufford. In one situation, he determined the simple reaction time related to single targets of varying size and brightness. It was found that for targets of "high" luminance (2067 mLamberts, in this case) there was little variation in reaction time (about .190 sec.) with increasing size above 44 minutes visual angle. Below 44 minutes, there was a slight (about 10 msec.) increase in reaction time at 20 minutes VA. For luminances at and below 20.7 mL there was found to be a continuous, but non-linear, decrease in reaction time with increasing target size from 20 minutes to 190 minutes VA, with the most significant differences in RT between the smaller target sizes. At "low" luminance the RT data are very similar at all target sizes from 20 to 190 minutes of visual angle (Hufford: 1370-71). The data

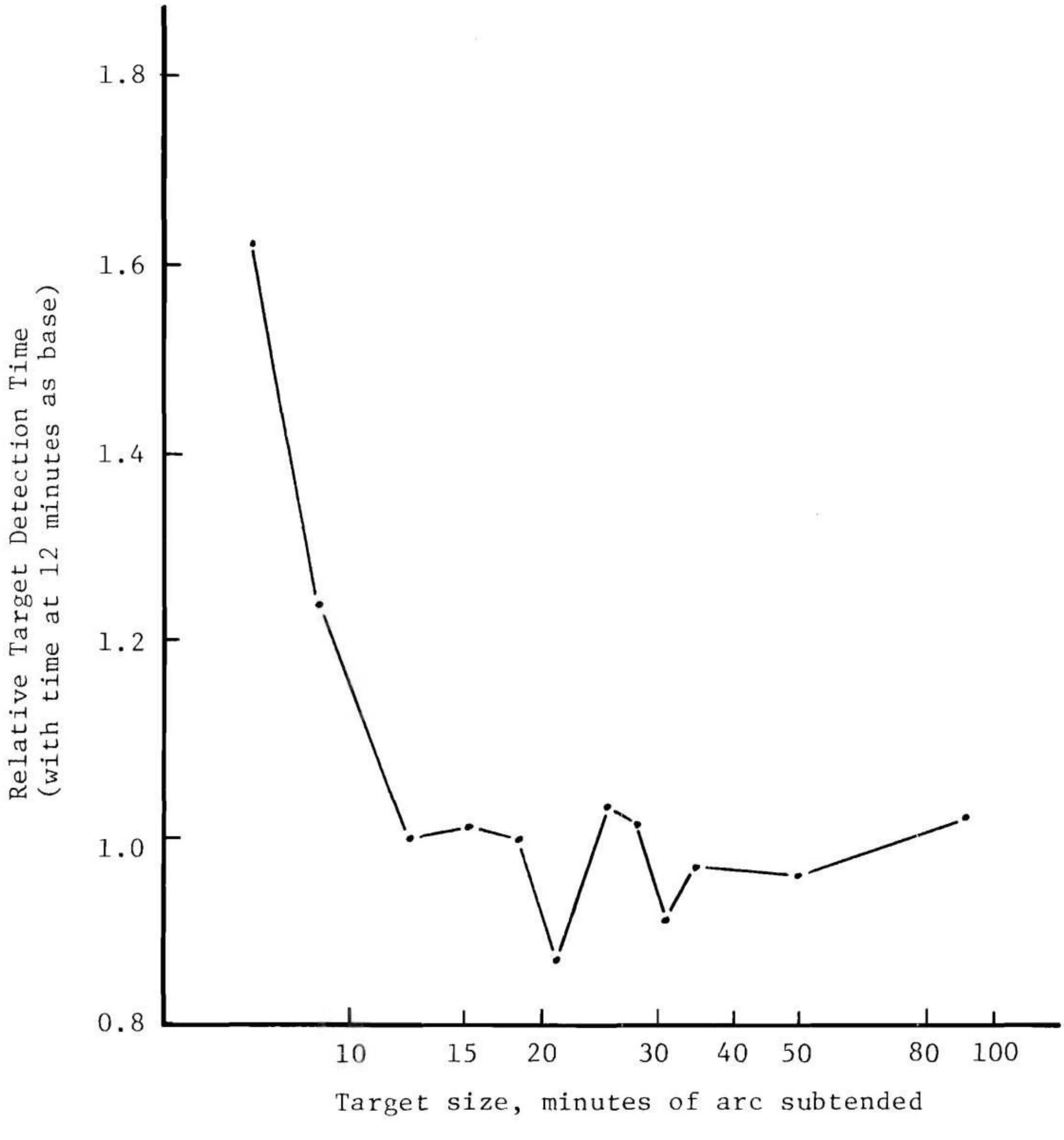

Figure 2-1. Identification Time vs. Target Size (after Steedman and Baker).

for this situation is shown in Figure 2-2.

The other situation investigated by Hufford consisted of determining the simple reaction time to a visual stimulus of constant area dispersed over a field of varying size and of varying luminance. The target or stimulus in this case was an array of five equi-sized circular spots arranged as a square with a spot in the center. In this case it was found that visual angular dispersion of the target had no effect on RT at the two higher luminance values used, 20.7 mL and 2067 mL. At the lower luminance values it was found that reaction time increased with the total visual angle of the field occupied by the stimulus, as shown in Figure 2-3 (Hufford: 1370).

In a study by Harris concerned primarily with eye focus time, but which contains much data on one-bit choice reaction times, those reaction times for targets subtending smaller visual angles (1-4 minutes) were developed. The target in this case was in a fixed location and was surrounded by a field devoid of irrelevant targets; the experimental conditions in this study were quite similar to those in Hufford's studies. The relationship between target size and the reaction times mentioned above is shown in Figure 2-4. The values shown are consistent with Hufford's results for his "single target" situation, if his curves were extended to lower values.

Size of Field

Baker, Morris, and Steedman determined that the time required for detection of a particular target increased linearly with the size of the field scanned for the target, in cases where visual noise or clutter intensity remains constant. This particular variable is also a primary

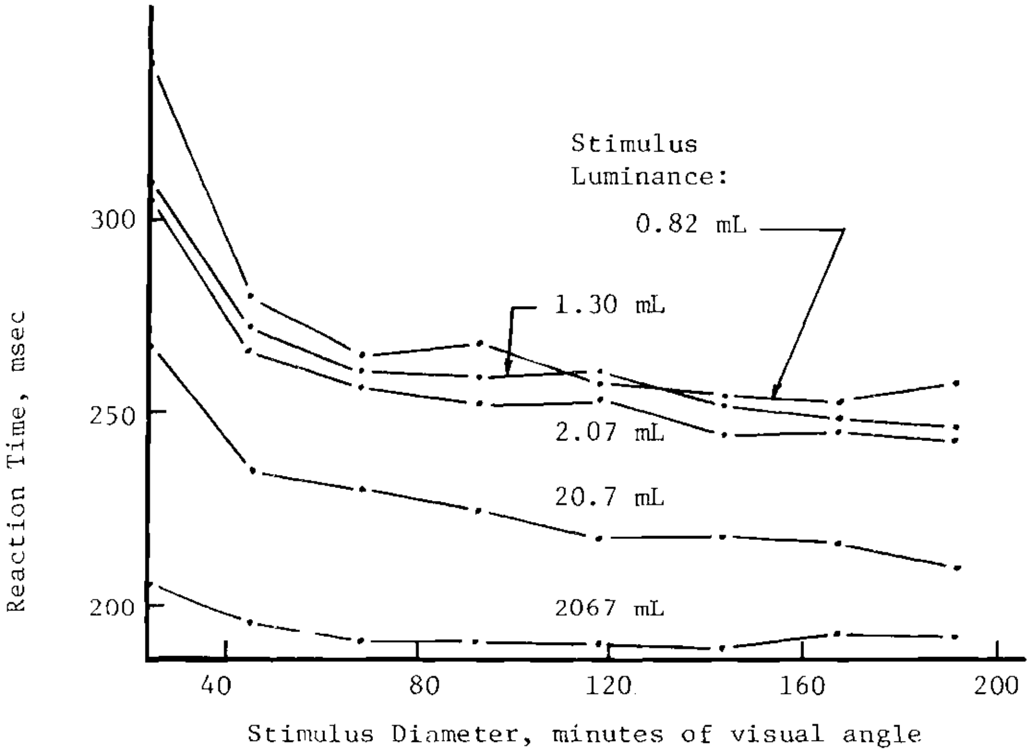

Figure 2-2. Reaction Time vs. Stimulus Diameter (after Hufford).

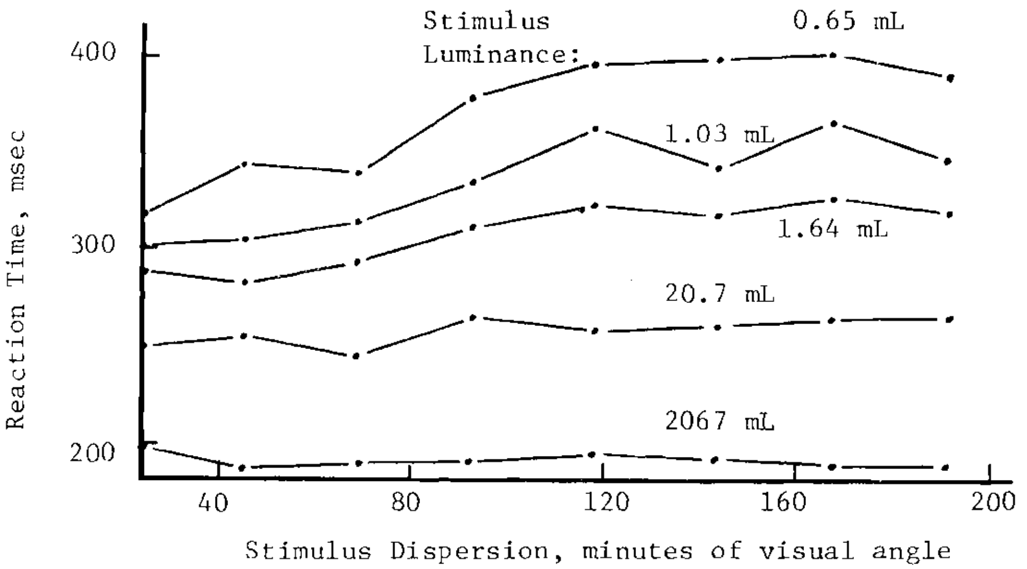

Figure 2-3. Reaction Time vs. Stimulus Dispersion (after Hufford).

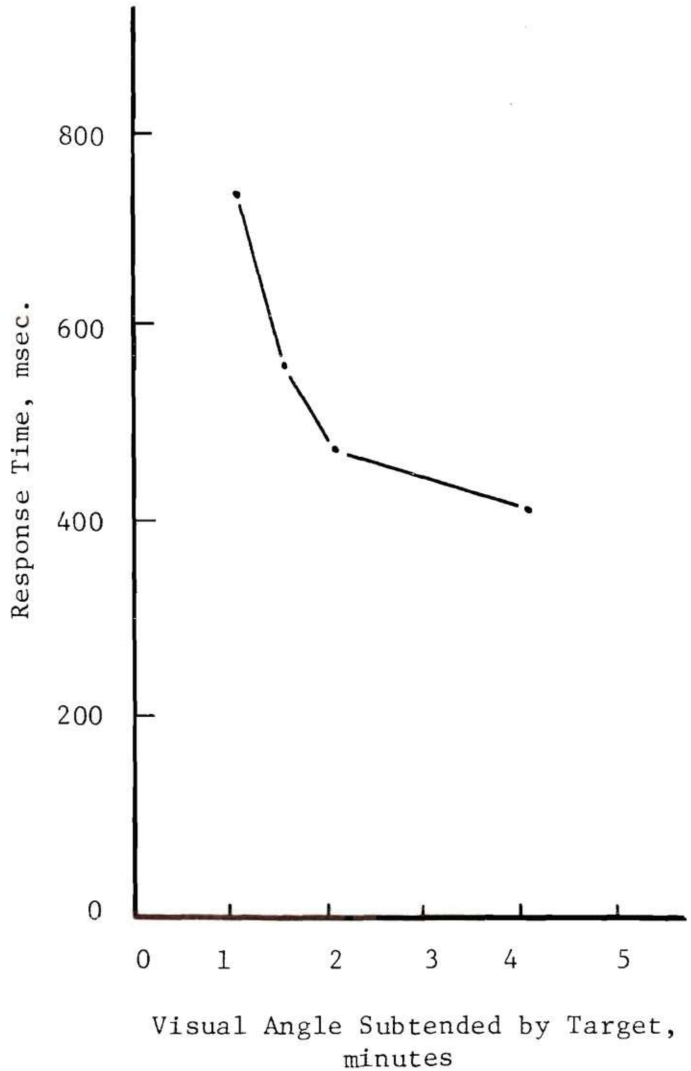

Figure 2-4. Response Time vs. Target Size (after Harris).

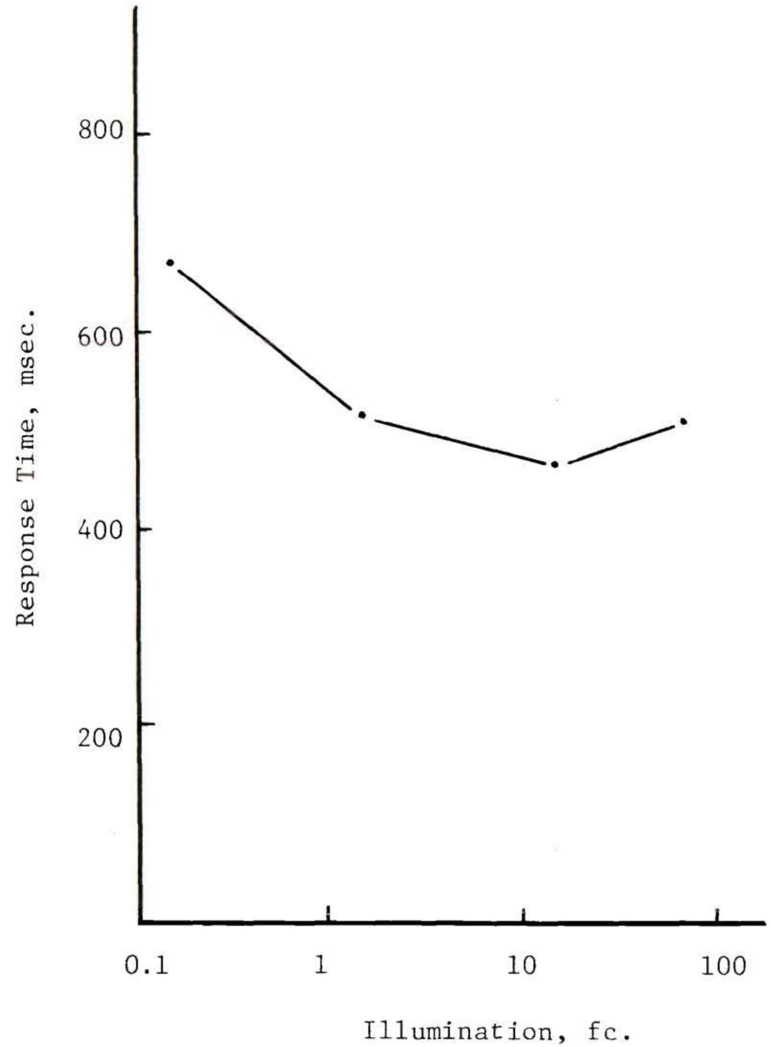

Figure 2-5. Response Time vs. Target Area Illumination (after Harris).

variable in the Work Factor system for determining times to "inspect" (Maynard: 5-87). In that system the time allowed for detecting the target is determined essentially by comparing the probable target size with the overall field size, smaller targets and larger fields resulting in longer detection times.

It might be noted at this point that, although time necessary to detect, locate, or identify a target is not actually time spent in the mental process of making a choice, it is time that must be included in the overall allotment of time for an industrial decision-making task, in those cases where it occurs.

Illumination

The relationship between target illumination and response time for targets with no location uncertainty and no clutter in the field can be seen from data extracted from the work of Harris, mentioned earlier. From that study data can be extracted illustrating the time required for a one-bit choice reaction under different illumination levels. This information is shown in Figure 2-5. Harris' data shows that as illumination of the target is reduced to lower levels, reaction time increases. Harris comments that the reaction time values are higher at the highest illumination level used (58 fc.) than at the next lower illumination level (14.5 fc.) because of target indistinctness caused by irradiation. He also ascribes the increase in reaction time as illumination decreases to an increase in the "uncertainty" of the target, similar to the uncertainty increase with increasing information content.

A primary effect of illumination in the work place, and specifically in the target area, has been found to be in error rate, as well as in target detection times. Error rate as a function of illumination on the target has been found to have a characteristic form, generally as shown in Figure 2-6, which illustrates the effect of illumination on dial reading errors. The shape of this curve, essentially constant at values above a particular value (about 0.03 ft-L. in Figure 2-6) and sharply increasing as target illumination decreases at lower values, holds for various tasks and target characteristic. The parameters of these curves vary, however, for these different tasks and targets. In general, tasks involving small targets and fine detail tend to move the curve to the right (increase the minimum illumination required) as do tasks involving low contrast between targets and the field that surrounds them (Van Cott and Kinkade: 51).

The procedure indicated by these illumination considerations, then, is to treat illumination as a factor that may affect choice reaction time, and also to handle it as a factor in workplace design that may have an effect on reliability in job performance. The Illuminating Engineering Society Lighting Handbook offers design recommendations for illumination level and type of illumination for particular task conditions.

Target Contrast

Target contrast has been found to be interrelated with other task variables, illumination level and target size. Generally, given fixed values for the other variables, as is reasonable in industrial tasks, the time to identify a target will increase as its contrast decreases. Also, for a particular size target, as background brightness decreases, the contrast required to detect the target increases

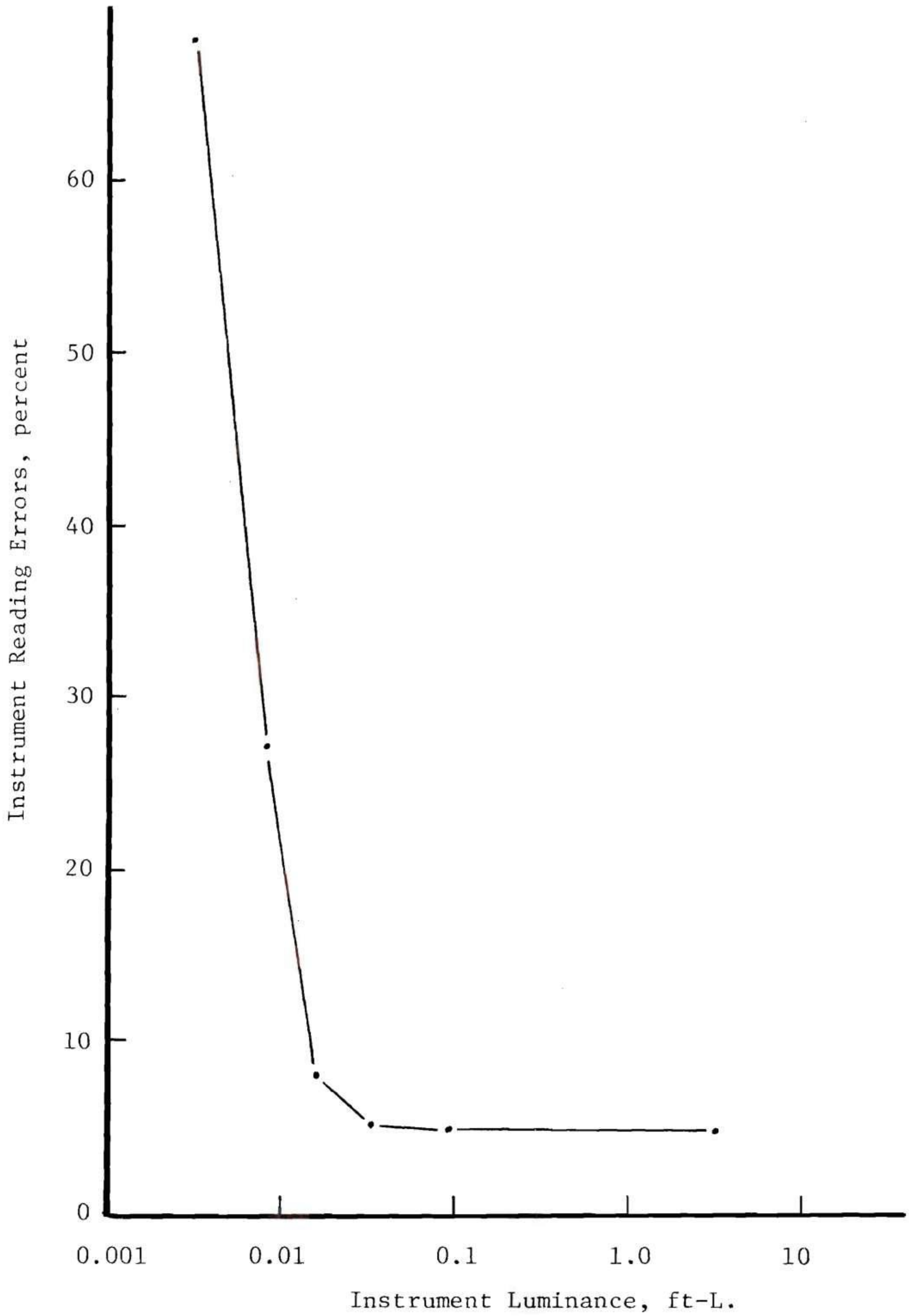

Figure 2-6. Error Rate vs. Illumination (Dial Reading) (from Van Cott and Kinkade).

(Van Cott and Kinkade: 51). Target contrast is an entry variable in the Work Factor "inspect" element (Maynard: 5-87).

Target Difficulty

In the study mentioned earlier under Size of Field, having to do with the relationship between target size, resolution, clutter intensity, and search time, Baker, Morris, and Steedman identified a relationship between the "difficulty" of a target and the speed with which it can be located and identified in a cluttered field. They quantified the difficulty of a particular target by calculating the ratio of the target area to the area of its minimum circumscribing circle. In these terms long, strung-out targets develop lower values for the ratio stated above, and conversely, compact, "blocky" targets develop higher values. As would seem reasonable, the stretched-out targets with low ratio values were located and identified more quickly and reliably than those targets with higher ratio values. These investigators developed a linear relationship between both search time and errors and the ratio stated above, an index of target difficulty (Baker, et al.: 54).

Clutter in the Visual Field

In the same study mentioned immediately above, Baker, Morris and Steedman determined that as the number of irrelevant targets in the field (clutter) increases, search time or time for location or detection of the relevant target increases proportionally (Baker, et al.: 53). (See Figure 2-7.) The corrollary to this is that as search time is limited by speed stress, the number of missed or misidentified targets will increase (Van Cott and Kinkade: 58). Another study, one related to that cited above and done by Steedman and Baker, showed that increasing the field

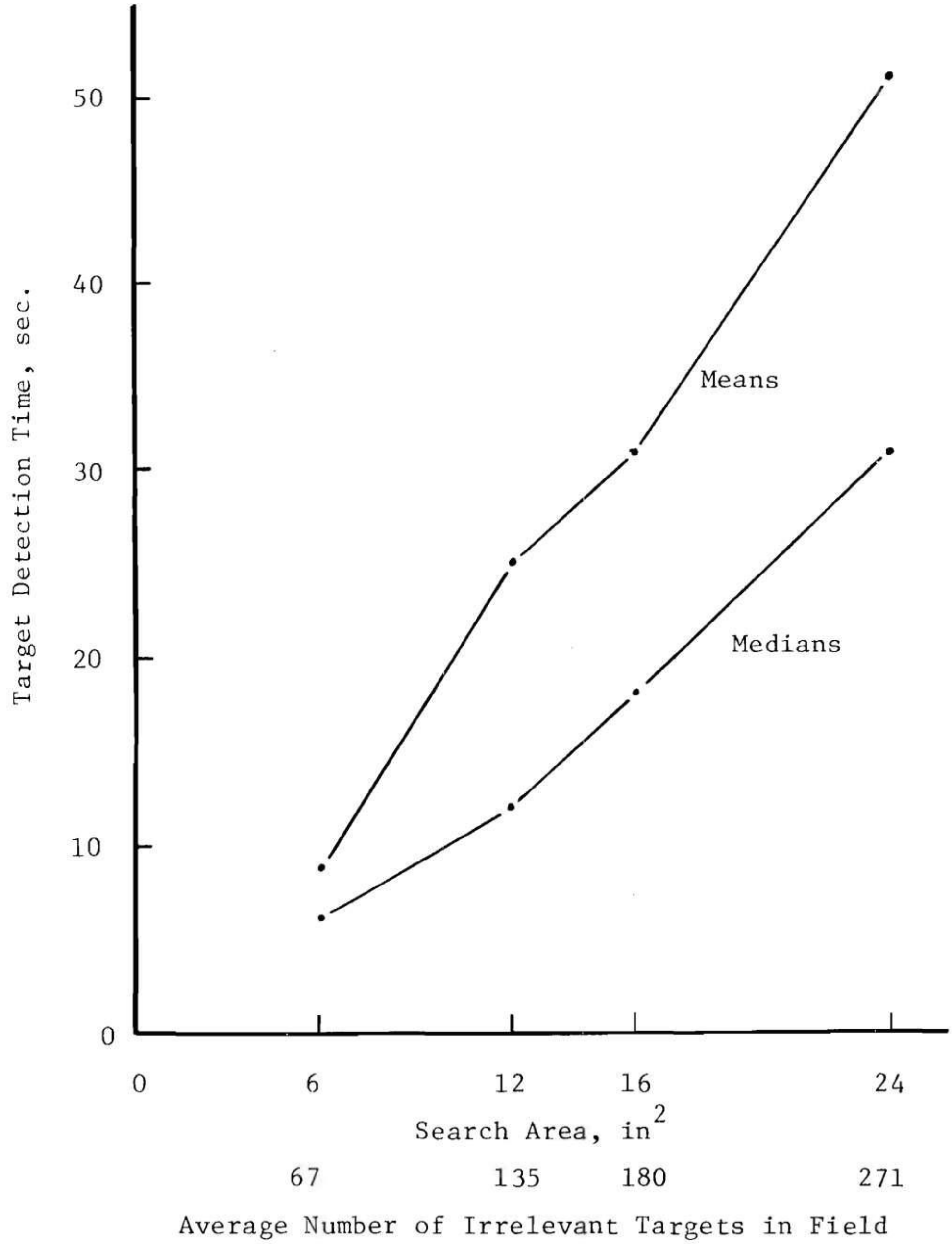

Figure 2-7. Detection Time vs. Field Size (after Baker, Morris, and Steedman).

size while proportionally decreasing the clutter intensity (or maintaining the number of irrelevant targets in the total field constant) results in no change in detection time (Steedman and Baker: 126).

Target Movement

The primary effect of target movement is that of reducing the visual acuity of the individual searching to detect a target stimulus. In other words, the smallest detail that can be detected on a moving target is larger than the smallest detectable detail on a static target; furthermore, the difference in static and dynamic visual acuity increases as target speed increases. Dynamic visual acuity is affected by age and slightly by sex, as shown in Figure 2-8. Values extracted from this graph for 46-year-old males illustrate the effect of increasing target speed (Table 2-1).

TABLE 2-1. Target Speed vs. Dynamic Visual Acuity

Angular Velocity of Target	DVA as a Proportion of Static Acuity
60° per second	1.3
90° per second	1.6
120° per second	2.0
150° per second	2.7

Information Content

(The reader is referred to Sheridan and Ferrell, Chapters 2 and 5, for a more detailed explanation of information processing theory.)

Information Conservation. It has been determined that the amount of information, in the sense of the Shannon-Wiener measure of information, that is either transmitted or reduced by an individual

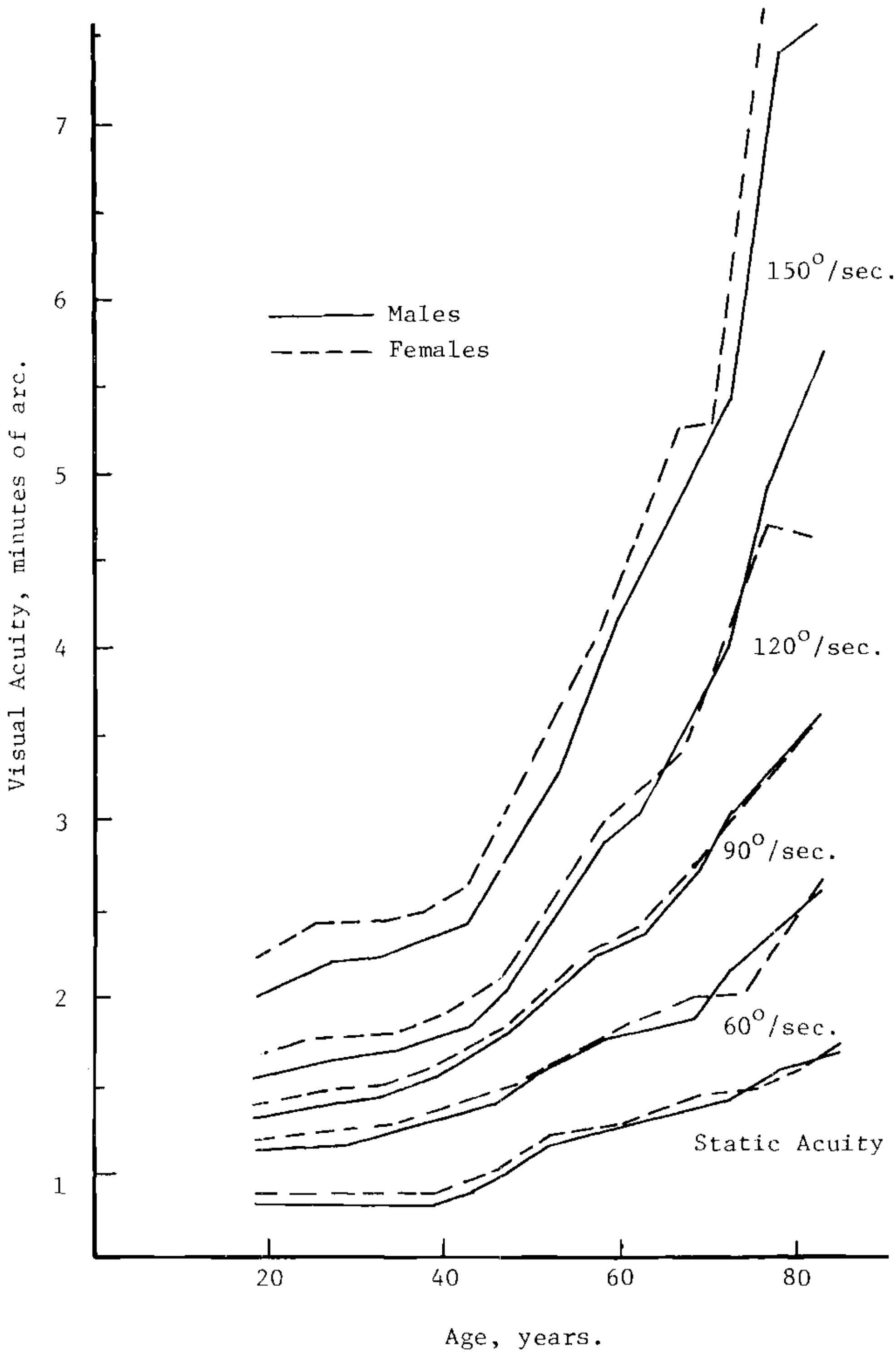

Figure 2-8. Visual Acuity vs. Age, Sex, and Speed of Target Movement (after Burg).

in accomplishing a mental task has an effect on the time consumed in that process.

According to Information Theory, the amount of information H(x), contained in a set of possible occurrences, such as the condition of products undergoing inspection, can be expressed as:

$$H(x) = \sum_i p(x_i) \log_2 \frac{1}{p(x_i)}$$

where the x_i's are the various possible occurrences (e.g., acceptable, requiring rework, unrepairable, etc.) and $p(x_i)$ represents the probability or relative frequency of event x_i. Such a set of events can be considered as stimuli presented to an individual for information processing. The responses that the person makes in reaction to these stimuli can be considered as another set of events, and the information content associated with each, the stimuli set and the response set, can be determined as above. When the number of categories is equal in the stimulus and response sets, information conservation occurs.

In the situation wherein the decision-maker/information processor makes no mistakes, always correctly associating response with stimulus, the information content in each will be equal, and all the information in the input will be transmitted to the response set. This is somewhat unrealistic, however; usually the information processor either fails to recognize appropriate stimuli (errors of omission), associates an improper response with a stimulus (equivocation) or responds when no stimulus is actually present ("noise"). All of these errors tend to reduce the information actually transmitted from the stimulus set to the response set in handling the information.

If input information (in the stimulus set) is represented by $H(x)$ and the information contained in the response set is $H(y)$, the information transmitted from x to y is the correspondence between the sets, or the intersection between $H(x)$ and $H(y)$. This quantity is $T(x;y)$ and is determined by set theory as $H(x) + H(y) - [H(x) \cup H(y)]$. The quantity $[H(x) \cup H(y)]$, the union of sets $H(x)$ and $H(y)$, can be called $H(x,y)$ and consists of the information contained in the total of the individual x,y pairs:

$$H(x,y) = \sum_i \sum_j p(x_i,y_j) \log_2 \frac{1}{p(x_i,y_j)}$$

where $p(x_i,y_j)$ is the relative frequency of stimulus x_i being associated with response y_j.

It has been determined that the quantity developed above, $T(x;y)$, the information transmitted in an information processing task, is related to the time necessary to process the information. A relationship developed by Bricker and Hyman states that:

$$\text{Choice Reaction Time} = a + b\ (\log_2 n)$$

for cases where the possible stimuli are equiprobable, there being n of them. The parameter a, above, represents simple reaction time (Welford: 195). For cases involving nonequiprobable events and errors or omissions this relationship becomes:

$$\text{Choice Reaction Time} = a + bT(x;y).$$

This relation simply illustrates the well-known trade-off between speed and accuracy in the performance of a mental task; in other words, as reaction time is reduced, information transmitted will also be reduced, the reduction occurring in the form of errors or omissions.

A primary difficulty in dealing with information transmitted as a variable in a predetermined motion-time system is that it cannot be determined "before the fact"; it will vary with each operation and can only be determined by comparing the information processor's response set with the information input set he receives. A manner in which this problem can be dealt with will be presented later.

Information Reduction. Another type of information processing task, other than transmission (information conservation), is information reduction. Information reduction occurs when the processor takes in larger amounts of input information but produces, purposeful y, a smaller amount of output information. A realistic example of this type of processing would be the executive decision-maker who considers a large amount of data to produce a yes-or-no (one bit) decision.

It has been determined that the amount of information reduced (calculated as the difference between the input and output information content) has an effect on information processing time (Rabbitt:1212). This effect was essentially that a greater information reduction called for longer processing times. Posner, in a 1964 study, found this effect to be linear up to 40 bits of information reduction (Posner: 463).

Many industrial tasks involve information reduction, the most obvious being the inspector who observes production items in many slightly varying conditions but grades them into a few, or possibly just two, categories.

Discrimination Required. A third type of task which involves information processing and which may be found in industry is one of discrimination. Such a task could involve discriminations between two targets presented simultaneously or between a target presented visually and the "ideal" or "model" object which exists either in the operator's memory or physically at the work place.

Welford illustrated the relationship between time for discrimination and the dimensional difference between two targets. He plotted data developed by Birren and Botwinick by having subjects select the longer or two lines presented simultaneously; the resulting plot is shown in Figure 2-9.

Significant aspects of the plot and Welford's interpretation are:

- the "flattening" of the curves for differences above 10% seems to indicate a lower limit to discrimination time.

- the convergence of the regression lines (fitted by least squares for points at 10% and less difference) near the zero information line suggests simply a decreasing rate of information gain with age.

- the difference in that point of convergence (about .28 sec) and the minimum time for young subjects (about .59) corresponds to the time commonly found for two-choice reaction by subjects of that age group.

- the .28 sec convergence point for zero information was taken to be an apparatus or procedural delay.

The overall interpretation of this data is that the mental processes of discriminating which line was longer and choosing the appropriate response went on simultaneously. For situations where the difference was obvious (greater than 15%), the discrimination took less time than the two-choice reaction. Therefore, a constant two-choice

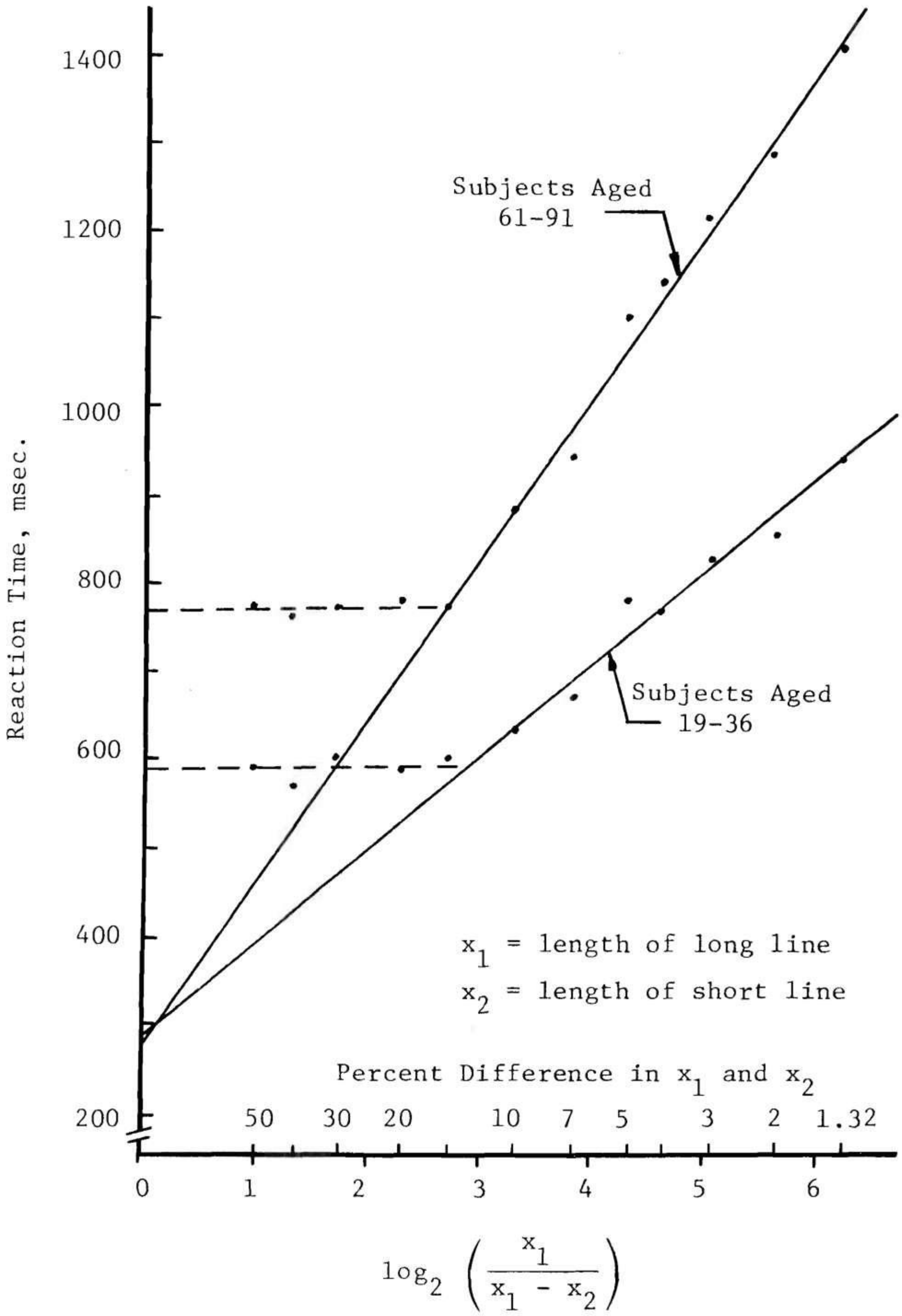

Figure 2-9. Reaction Time in Discrimination (after Welford).

reaction time prevailed. For situations where the difference was not so clear-cut (less than 15%), discrimination time took longer and increased with decreasing difference. For the range where dimensional difference is zero to 10% of the longer dimension, the equation:

$$\text{Discrimination Time} = K \log_2 \frac{x_1}{x_1 - x_2}$$

has been fitted, x_1 being the longer dimension and x_2 being the shorter (Welford: 215). This formulation has been extended as:

$$\text{Discrimination Time} = K \log_2 \frac{I}{\delta I}$$

where I is the physical intensity of a particular stimulus and δI is the difference between that intensity and that of another stimulus. This model would only be useful for situations wherein the stimuli are those to which human senses respond linearly.

Speed and Load Stress. The rate at which recurring stimuli are presented (speed stress) and the number of stimuli sources to which the decision-maker must attend (load stress) have an impact on the detection of stimuli, but the effect involves reliability of detection rather than time for detection or choice-making. Recognition of targets in complex fields improves as available viewing time increases (Van Cott and Kinkade: 59), but as speed and load stress are increased, reliability in detection is reduced. It has been proposed that errors or omissions increase logarithmically with speed stress and load stress, as shown in Figure 2-10 (Conrad: 5).

Operator Age. It has been determined that an individual's reaction time will increase with his age. This is apparently true for

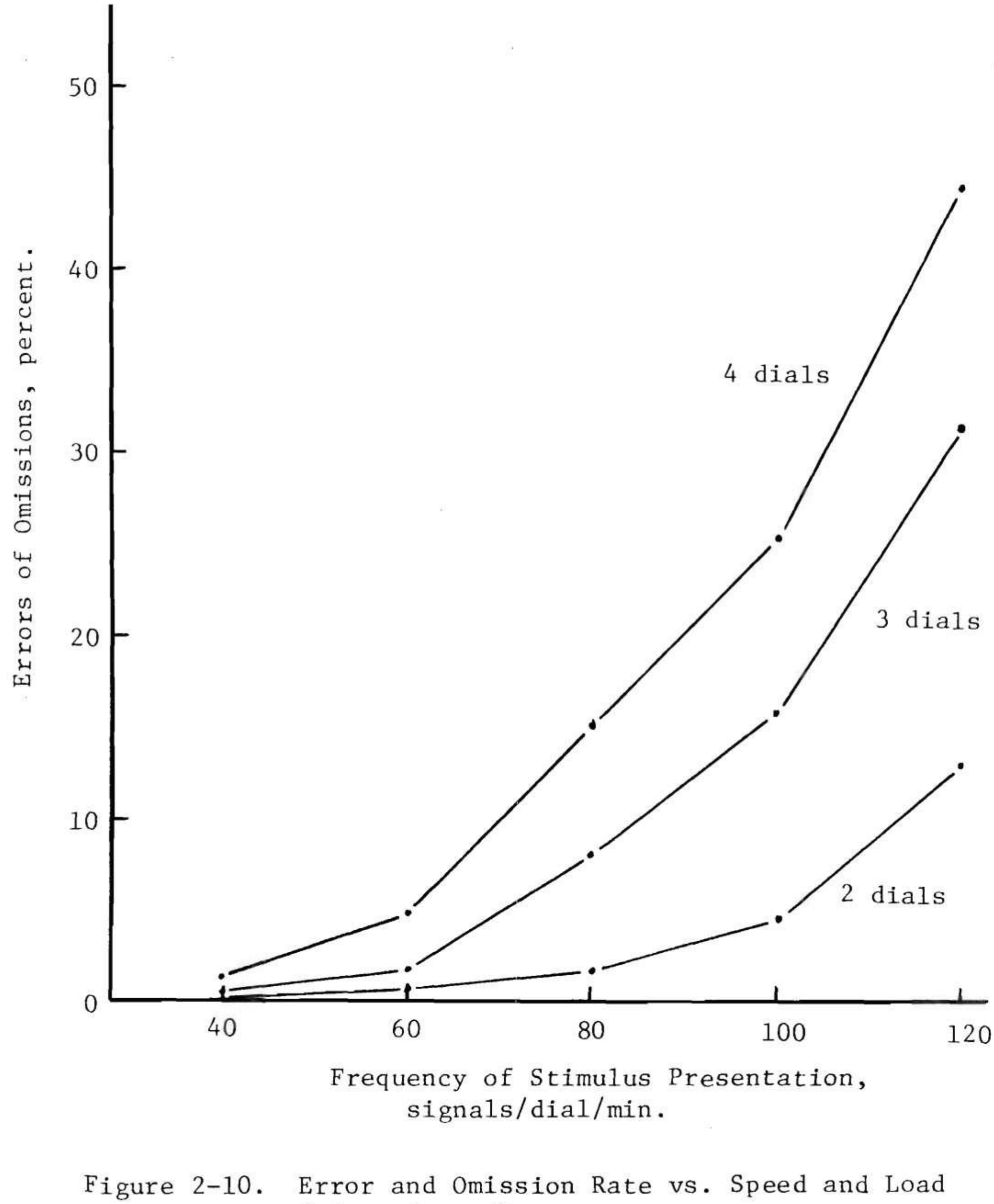

Figure 2-10. Error and Omission Rate vs. Speed and Load (after Conrad).

both simple reaction time and the additional increment occurring in choice reaction time. Referring to the interpretation of Figure 2-9 under Information Content, it will be recalled that a slower rate of gain of information (longer choice- reaction times) was obtained for subjects in the 61-91 age group than for subjects in the 19-36 age group.

The degradation of information processing rate is aggravated by another phenomenon which occurs when the target moves. Returning to the section on Target Movement, it will be seen from Figure 2-8 that there is a marked degradation of dynamic visual acuity with age, indicating that older operators may miss observing small targets that other operators would reliably locate.

Temporal Uncertainty

Temporal uncertainty (uncertainty in the mind of the operator about when the next stimulus will be presented) is somewhat rare in industrial tasks to which predetermined motion-time systems would be applied, since the goal is generally to determine the regular pace at which the operator can perform. However, there are tasks involving temporal uncertainty, and its effect on choice reaction time should be developed. Alegria and Bertelson designed an experiment in which both temporal uncertainty and information content could be independently varied. It was found that temporal uncertainty seemed to add an independent quantity to choice reaction time above that created by information content of transmitted information. This amounted to about .055 sec when going from "low" temporal uncertainty (.5 sec warning prior to stimulus) to "high" temporal uncertainty (5 sec warning). This difference held regardless of information content. These findings indicate that temporal uncertainty has its effect on simple reaction time (parameter a in CRT = a+bT), rather than on the portion of choice-reaction time caused by the choice.

Summary

In recapituation, the literature has associated the following variables to either simple reaction time or "detection" time" - target size, field size, target movement, target "difficulty", clutter, and temporal uncertainty. Choice reaction time, on the other hand, has been related almost exclusively to information content as developed in situations requiring information conservation, information reduction, or discrimination. The age of the subject or operator has been found to affect both simple reaction time and information processing time, and there are indications that illumination and contrast also affect both of those time increments.

CHAPTER III

METHODS AND PROCEDURES

General

The variables chosen for examination in this experiment were target size, certainty f target location in the field, presence or absence of clutter in the field, and information content. Landholt rings were chosen as the visual stimuli, or targets. Landholt rings are circular images having a gap at one place in the ring; specifications of the image are that the gap width and stroke-width of the ring are equal and the outside diameter of the ring is five times the gap width. These targets can be varied in size and location and can be included with clutter having similar characteristics. The information content variable can be controlled by varying the number of possible orientations of the Landholt ring gap present in a set of stimuli.

The response of the subject to an individual stimulus was to activate one of eight switches on a small switchboard to correspond with the orientation of the gap of the Landholt ring stimulus. The switchboard was designed to provide stimulus-response compatibility (in order to eliminate that as factor confounding the experiment) and to provide equal movement distances from a finger rest to each switch. For a particular trial, the time between the presentation of the stimulus (illumination of an image on a rear-projection screen) and the subject's response (switch activation) was measured and recorded.

Equipment

An easily controllable, visually precise, and economical manner of stimulus presentation was determined to be illumination of a stimulus image on a screen by slide projector. The equipment used was a Kodak Carousel 800H audio-visual projector and a rear projection device, which provided some space economy and the removal of the projector from the immediate vicinity of the subject (see Figure 3-1). Slides were manufactured by photographing appropriately-sized stimulus images with Kodak High Contrast Copy Film. Example stimulus images, annotated with the variable levels represented by each, are shown in Figures 3-2 to 3-7; these illustrations are sized to provide the same activity at an 18 inch viewing distance as that used in the experiment. The dimensions of the entire slide image when projected were 14 inches by 22 inches (35.6 cm x 55.9 cm).

The subject was seated at a distance of 10 feet (3.05 m) from the projection screen with the response switchboard at hand. (See Appendix A for a diagram of the experimental layout and Figure 3-8 for the subject's position.) The eight response switches were arranged on the switchboard radially around and equidistant from a finger rest located in the center of the switchboard (see Figure 3-9). These switches were connected to an array of small lights (one for each switch) which indicated to the experimenter which switch was activated, and they were also connected to a Hewlett-Packard electronic timer, Model 5300A (see Figure 3-10). Also connected to the timer was a photoelectric cell placed in the beam of the slide projector. This photocell served to start the timer when each stimulus slide was projected, the timer then being stopped by the activation of a response switch by the subject. The elapsed time from

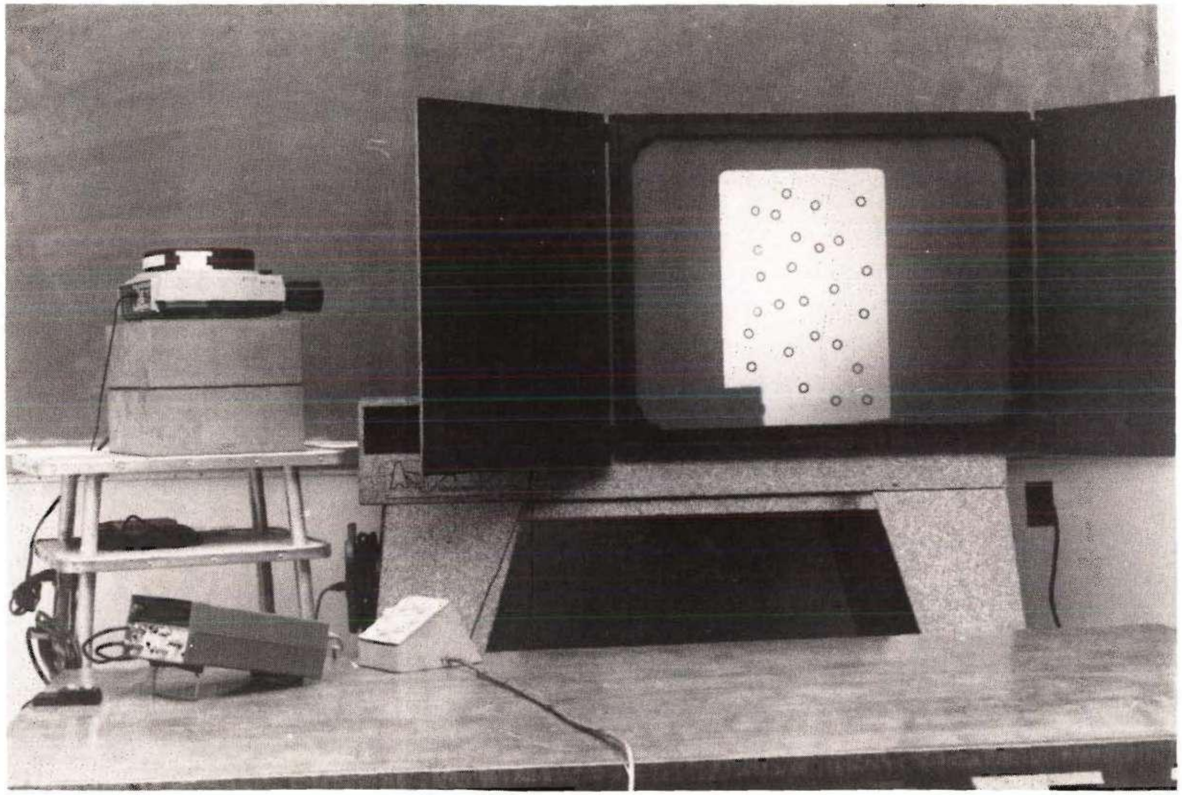

Figure 3-1. Projector and Rear Projection Screen.
(Timer and Response Indicator Light Panel in Foreground).

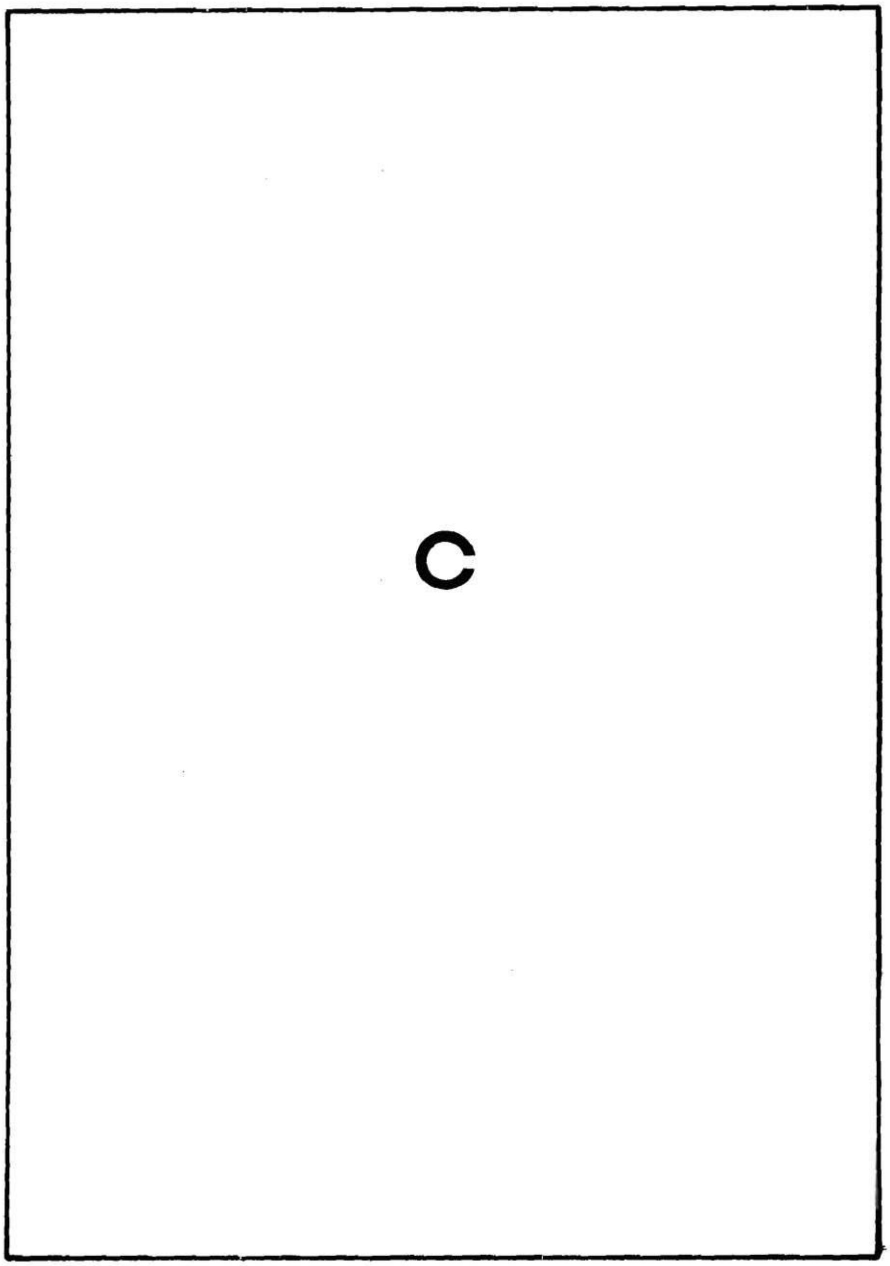

Figure 3-2. Large Target, Fixed Centrally, 1 Bit.

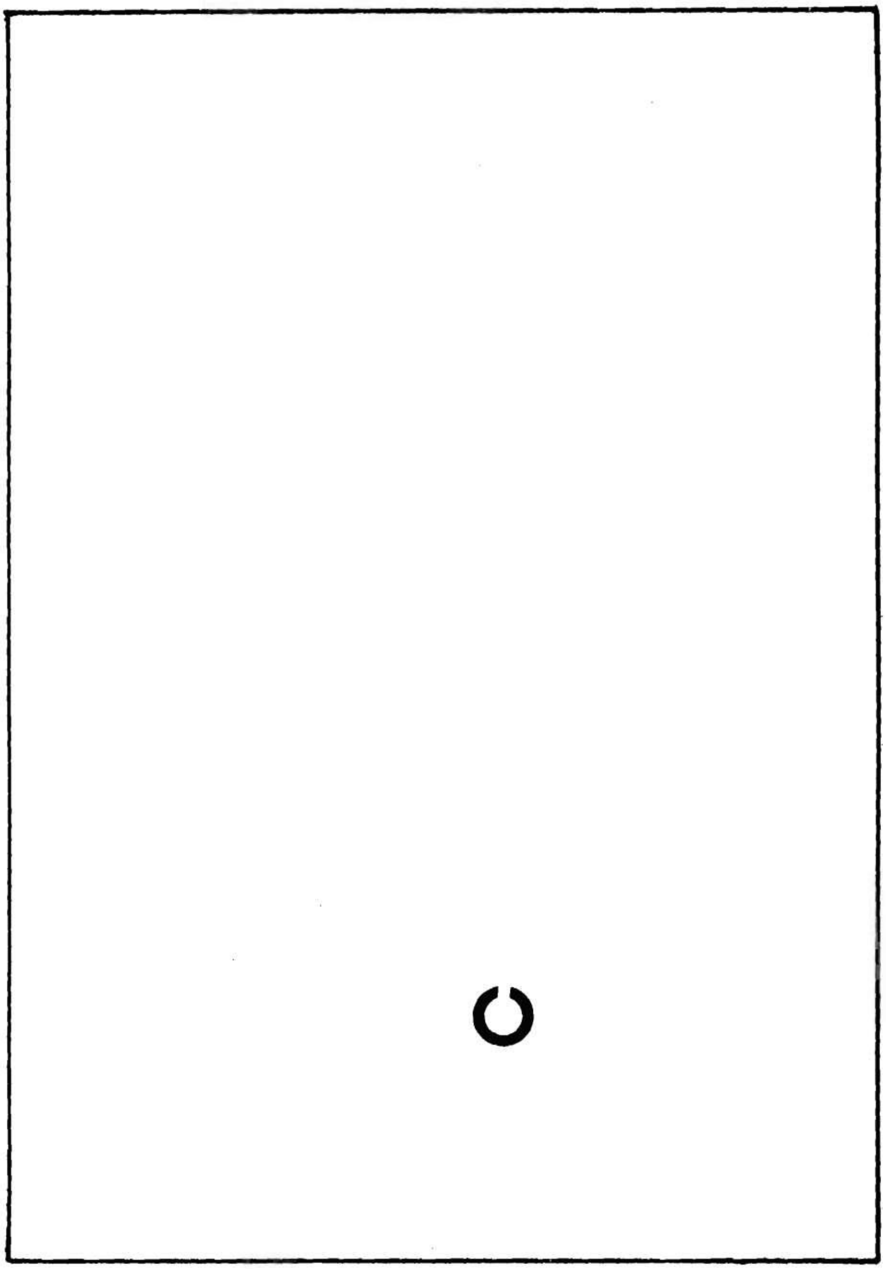

Figure 3-3. Large Target, Randomly Located, 2 Bits.

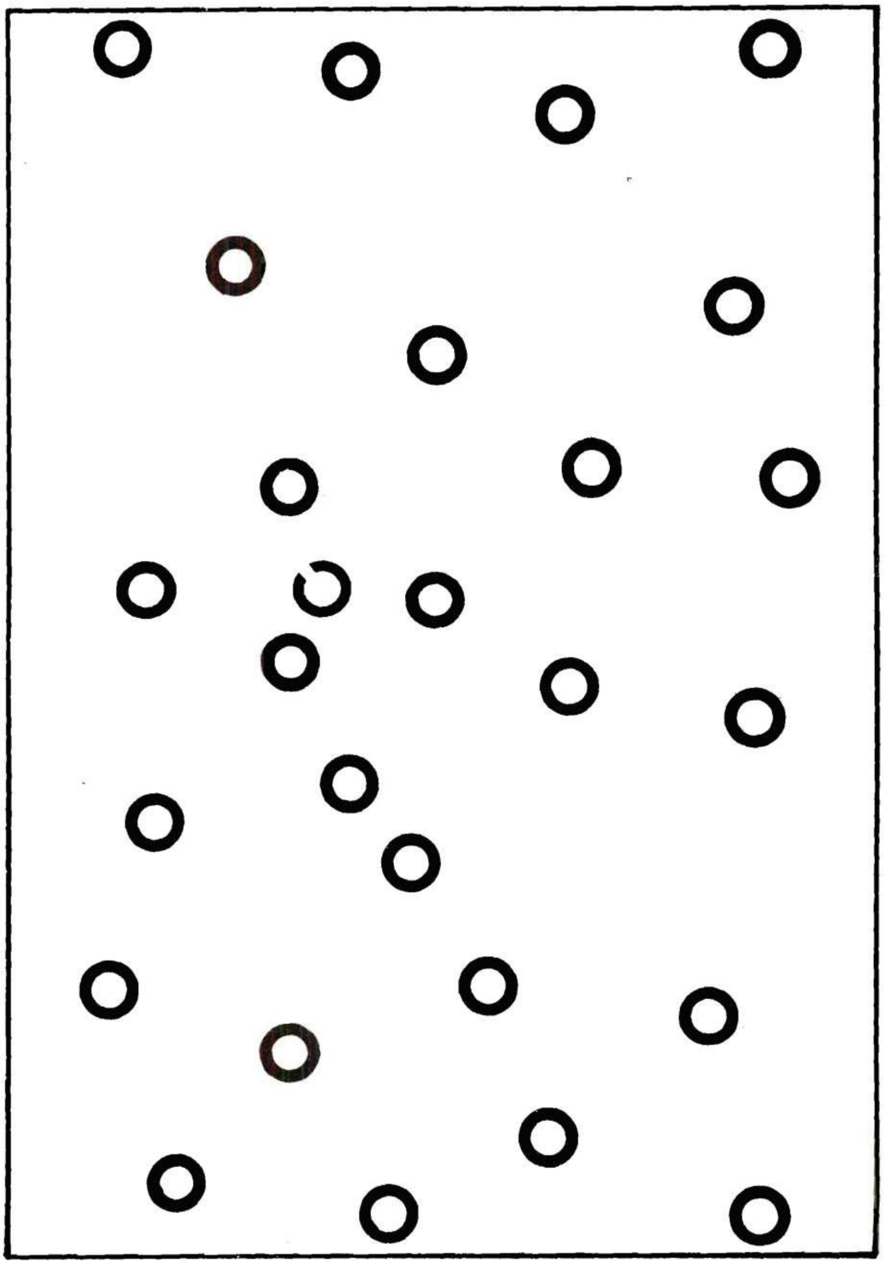

Figure 3-4. Large Target, Cluttered Field, 3 Bits.

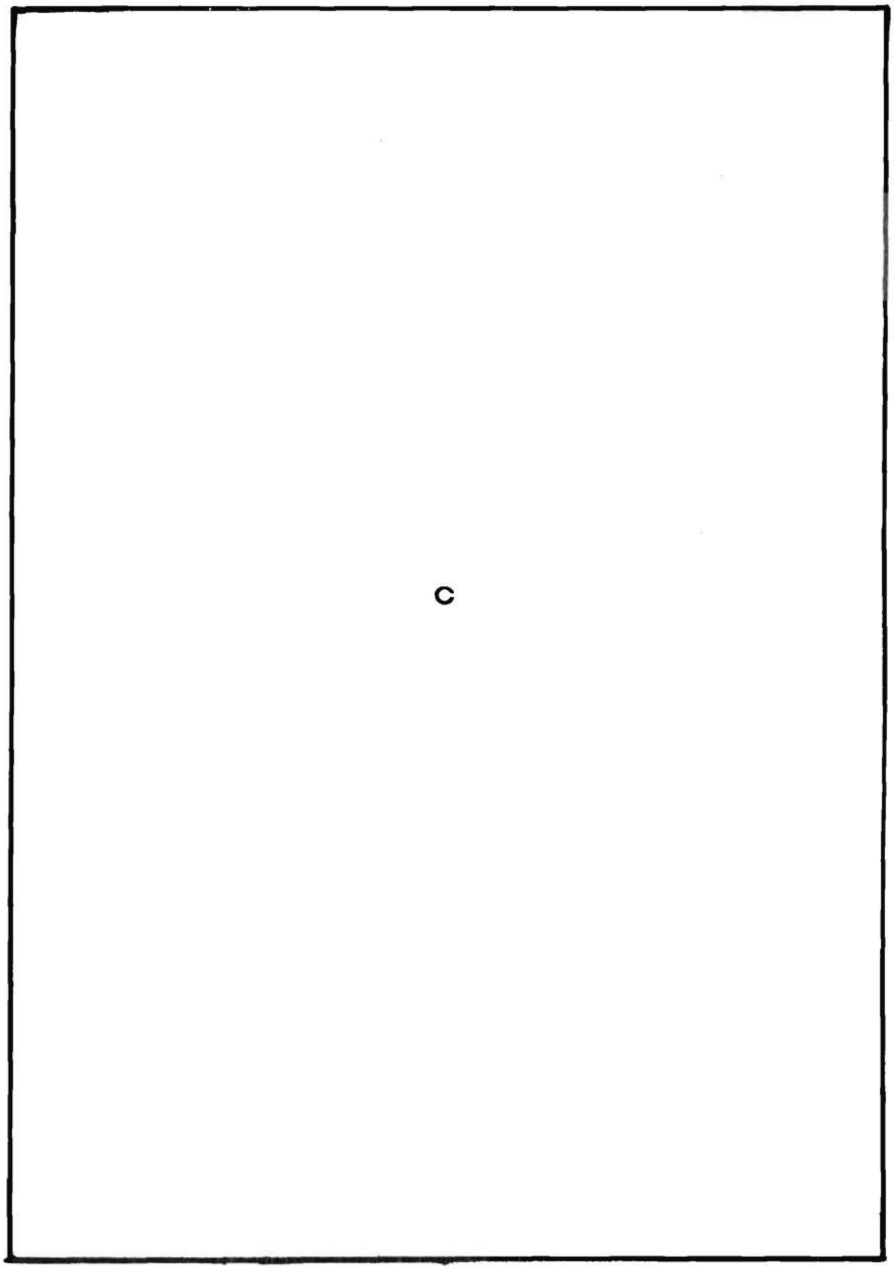

Figure 3-5. Small Target, Fixed Centrally, 1 Bit.

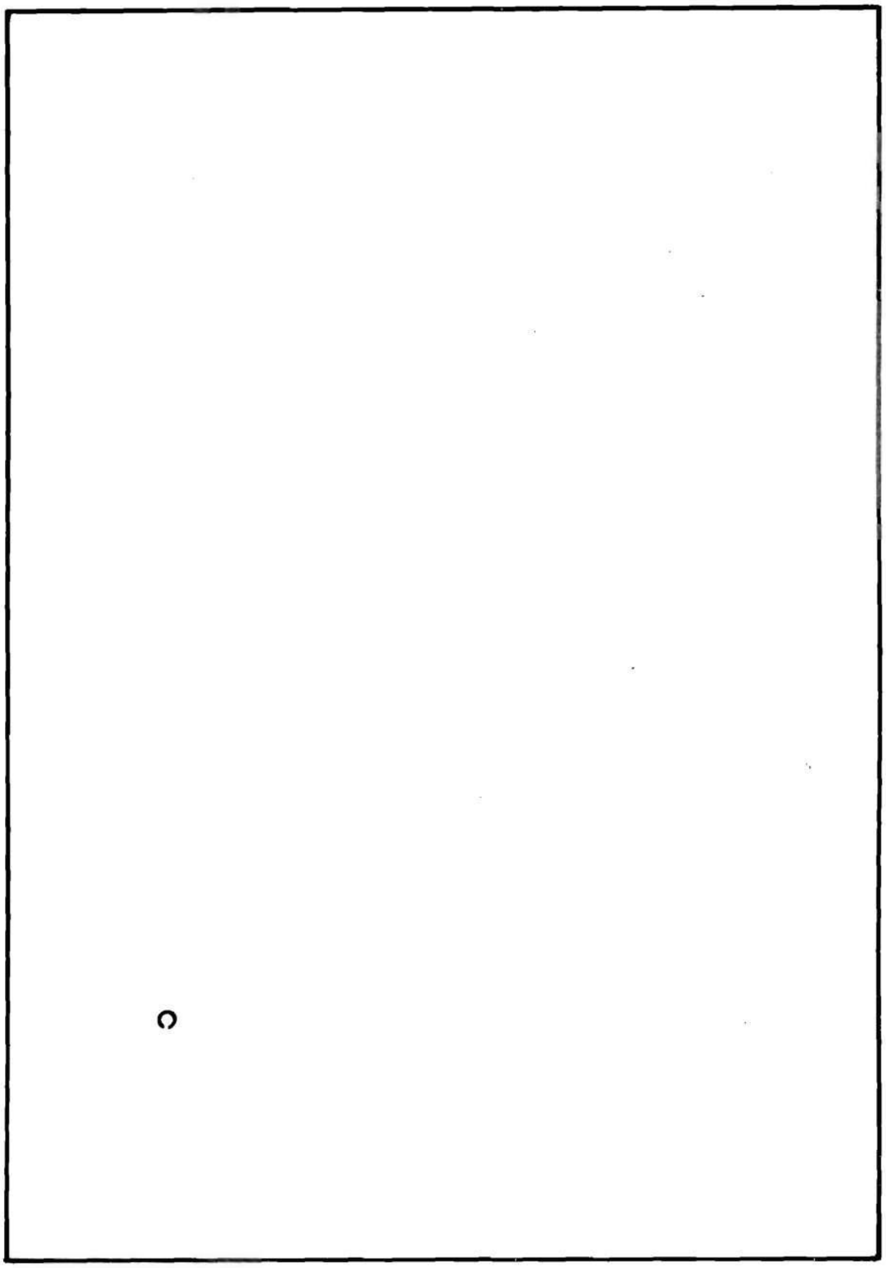

Figure 3-6. Small Target, Randomly Located, 2 Bits.

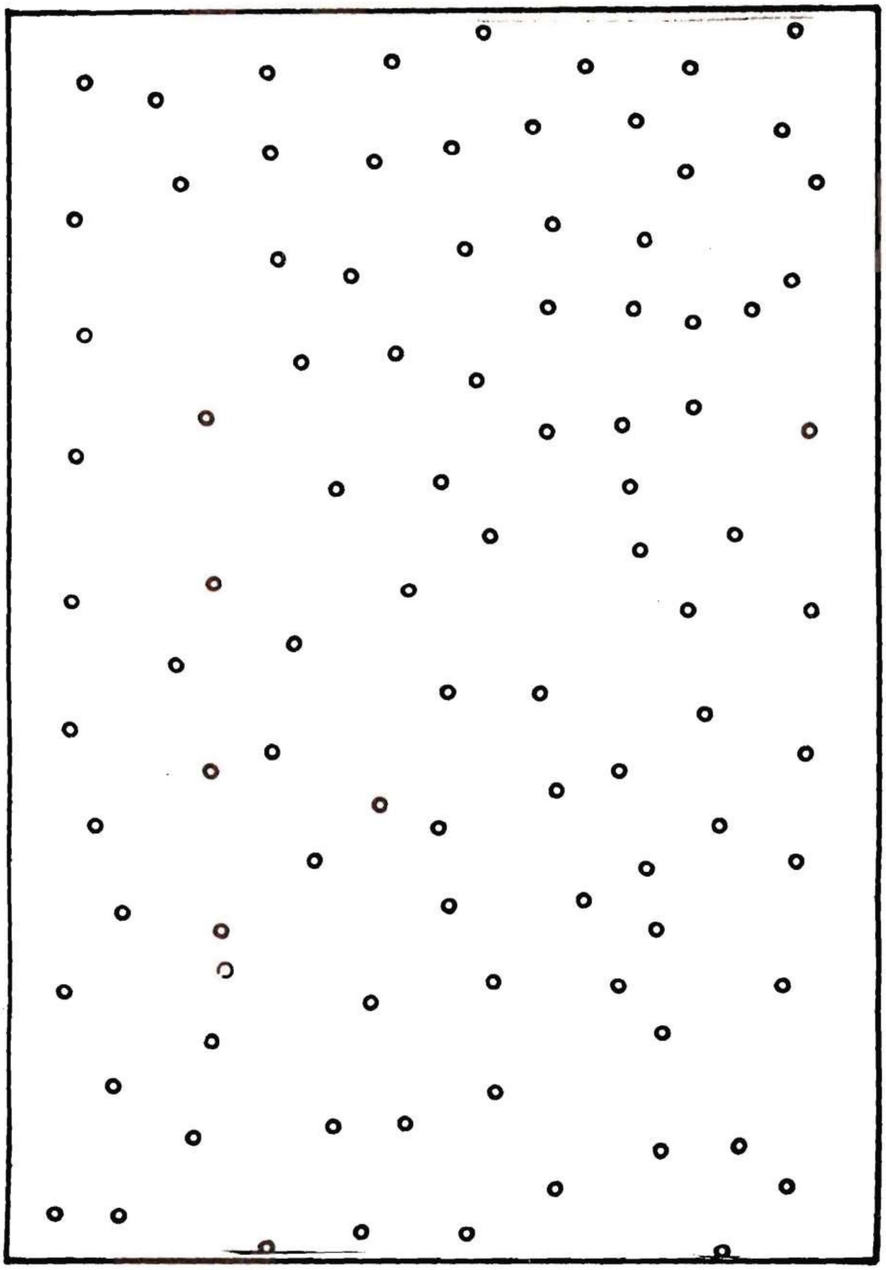

Figure 3-7. Small Target, Cluttered Field, 3 Bits.

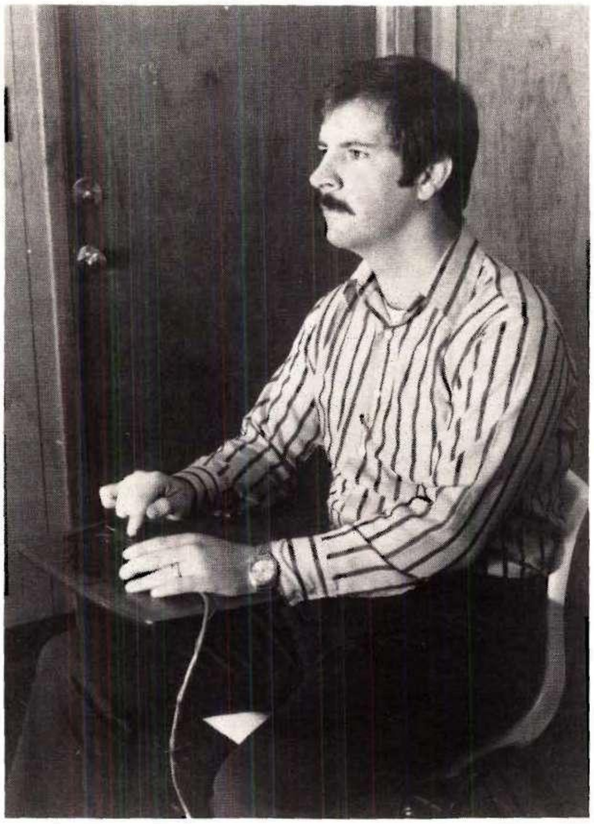

Figure 3-8. Subject's Position.

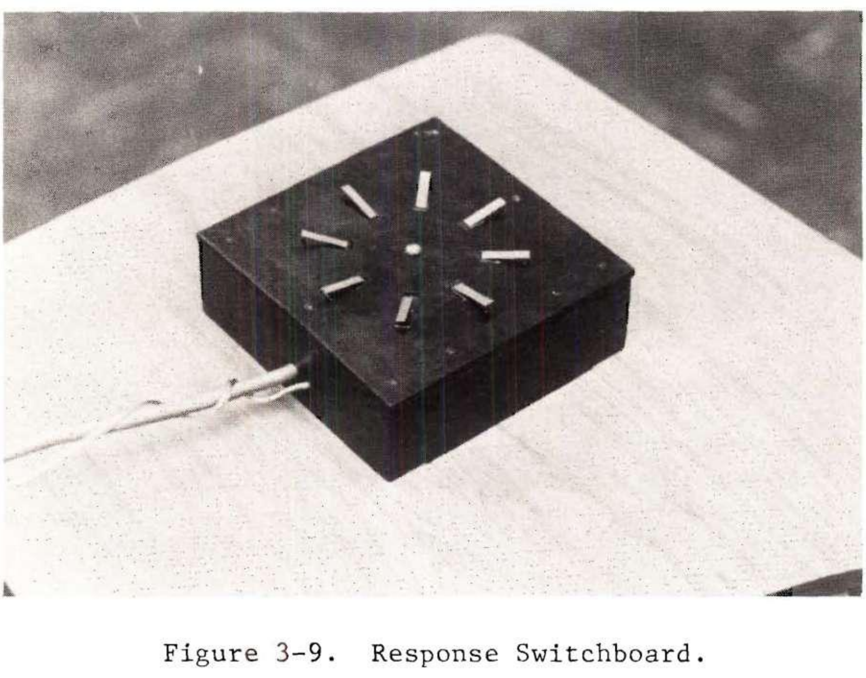

Figure 3-9. Response Switchboard.

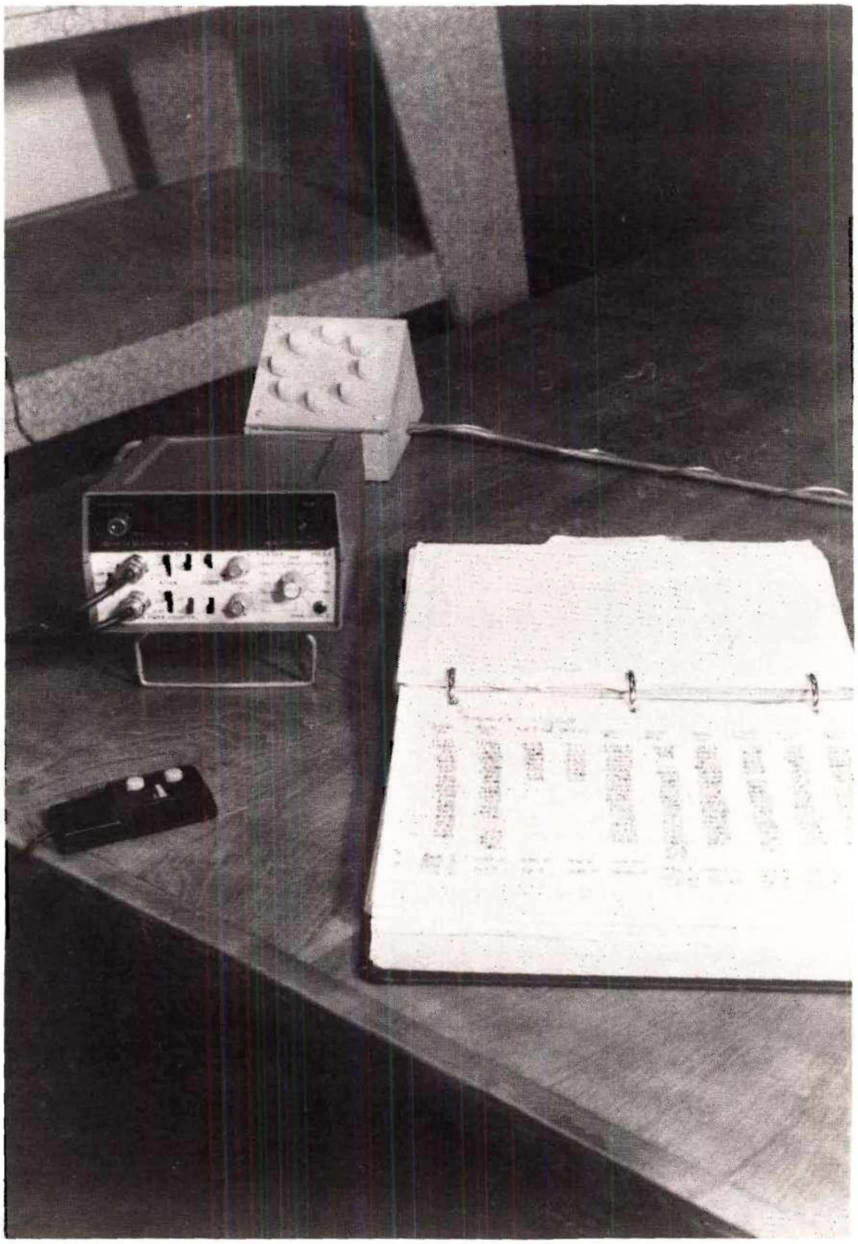

Figure 3-10. Experimenter's Station.
(Timer, Response Indicator Panel and Projector Control Shown).

slide presentation to response was digitally presented on the timer. (Appendix A provides an electrical schematic diagram for the experimental equipment.)

Variables

The stimuli presented to the subject varied in size (visual activity), certainty of location in the illuminated field, presence of surrounding clutter, and information content. The levels of each variable were as follows.

Target Size

It was decided with this variable, as with others, to investigate two levels - an easily identifiable target size and a target size near the margin of normal visual activity. The targets chosen, then, were Landholt rings with gap widths of five minutes of visual angle (20-100 acuity, termed the "large" target) and 1.5 minutes of visual angle (20-30 acuity, termed the "small" target).

"Degree of Confusion"

The two variables mentioned earlier, clutter and target location certainty, were combined in this study into one variable termed "degree of confusion". The levels of this variable investigated were:

- complete location certainty with no clutter (targets fixed in the center of an otherwise empty field), termed "fixed".

- complete location uncertainty (within the field) with no clutter (targets located randomly within an empty field), termed "random".

- complete location uncertainty with clutter (targets located randomly in a field containing a particular number of distracting images) termed "clutter".

The fourth possible situation within this variable, complete location certainty with clutter, was not considered to be meaningfully different from complete target certainty without clutter, so it was not included. In the situations involving distracting images, as can be seen in Figures 3-4 and 3-7, the clutter images consisted of rings essentially identical to the target Landholt ring except having no gap. Although the number of clutter images (unbroken rings) in the field differed for large and small targets within each level of target size, the number of clutter images was constant for all levels of information content. The number of unbroken rings surrounding large targets was 26, and 85 clutter images were associated with small targets.

Information Content

Information content was investigated at the one-, two-, and three-bit levels. These levels were manifested in the number of possible orientations of the Landholt ring gap in any stimulus presentation. Since, for equally likely alternatives, information content is determined by the logarithm (to base 2) of the number of alternatives, one bit is established by two alternatives, two bits by four alternatives, and three bits by eight possible alternatives. Therefore one bit of information content existed in stimuli where in the gap was oriented to the subject's left or right. Two bits of information was provided by gap orientations either straight up, straight down, to the left, or to the right. Similarly, three bits was established by the four orientations listed above plus the 45^{o} diagonal orientations - upper left, upper right, lower left, and lower right.

Subjects

As the objective of this project involved investigating a hypothesis which may provide a framework for estimating decision time, rather than developing firm numbers for a PMTS tabulation, a limited number of subjects were used. Subjects were six males trained in the engineering disciplines in the 25 to 37 age bracket; Table 3-1 provides information on each subject.

TABLE 3-1. Experimental Subjects

Subject No.	Initials	Age	Vision Corrected?
1	RKS	32	Not Necessary
2	TLS	37	Not Necessary
3	TC	32	Yes
4	MM	28	Yes
5	RA	31	Yes
6	BH	25	Yes

All subjects were generally interested in the project, although there were no specific incentives, monetary or otherwise, provided. Each subject was questioned to determine that their vision was at least as good as 20-30 in refraction when corrected and that they had no astigmatic condition which would affect the detection of targets due to target orientation. Had any subject shown difficulty in detection of the small (20-30 acuity) targets, they would have been excused from the experiment.

Experimental Design

To develop the data required for this analysis, a factorial design was chosen, combining all levels of all variables. Such a design involves 18 unique combinations of target size, "confusion", and information content. A pilot study revealed that the conditions involving clutter yielded reaction times that were considerably more variable than the times yielded by the other conditions, when 20 trials (stimulus presentations) were run for each condition. In an effort to reach heteroscedasticity, it was decided to utilize 40 trials for the conditions involving large targets in clutter and 80 trials for conditions involving small targets in clutter. These were divided into two and four sets of 20 trials, respectively, and each set was included as a separate condition in the experimental design. This resulted in 30 exposures to a set of 20 trials for each subject, even though there were only 18 unique conditions.

Those 18 conditions were arranged in a balanced sequence; the duplicates and quatriplicates of the clutter conditions were then filled into that sequence, also in a balanced manner. The resulting experimental design sequence is shown in Table 3-2. Each subject was exposed to the sequence in a different order, in an effort to balance the residual learning effects. Table 3-2 also illustrates the point in the sequence at which each subject started; each proceeded down the list of conditions and, for subjects 2 through 6, returned to the top of the list to complete the cycle.

Experimental Procedure

In order to facilitate scheduling and to minimize both fatigue and learning within the replicated conditions, the set of 30 conditions

TABLE 3-2. Experimental Design

	Target Size	Degree of Confusion	Information Content, bits
Subj. 1 started here	Large	Clutter	3
	Small	Fixed	1
	Small	Clutter	1
	Large	Random	2
	Small	Clutter	3
Subj. 2 started here	Large	Clutter	2
	Small	Fixed	3
	Small	Clutter	2
	Large	Random	1
	Small	Clutter	3
Subj. 3 started here	Small	Clutter	1
	Small	Random	3
	Large	Clutter	1
	Small	Fixed	2
	Small	Clutter	2
Subj. 4 started here	Small	Clutter	3
	Large	Fixed	1
	Small	Clutter	1
	Small	Random	2
	Large	Clutter	3
Subj. 5 started here	Small	Clutter	2
	Large	Fixed	3
	Small	Clutter	3
	Small	Random	1
	Large	Clutter	1
Subj. 6 started here	Small	Clutter	2
	Large	Random	3
	Small	Clutter	1
	Large	Fixed	2
	Large	Clutter	2

was divided into three sets of 10, each set requiring somewhat less than an hour of experimental time. The six subjects were then scheduled into 18 one hour periods.

As each subject began his sequence of conditions, he was given a brief explanation of predetermined motion-time systems in general and the specific objective of the experiment, in order to provide perspective and, hopefully, motivation. The conduct of the experiment was explained, providing examples of stimuli and specifying the desired responses. For standardization, the position of the subject's right hand and arm and the manner in which he should move his index finger in responding were specified. Although the experimenter was provided a means of monitoring the subject's responses to each trial, each subject was asked to state each time he realized that he had responded in error and also those times when he did not realiably strike the intended response switch.

At the beginning of each of the three one-hour experimental sessions that each subject went through, the subjects were provided a "warm-up" or practice period of 30 to 40 trials which developed hand coordination necessary to reliably strike all response switches. In addition, each subject was exposed to eight "simple reaction time" trials at the beginning and end of each one hour period. In these trials the subject was instructed to respond only to the presence of a stimulus on the screen (a large, fixed-location Landholt ring was used in all cases), ignoring the orientation of the gap. Also, he was instructed to strike each of the eight response switches, one for each "simple reaction time" trial. This procedure provided additional warm-up for the subject, structure for the experiment, and a simple reaction time estimate to compare with choice reaction time.

At the beginning of the presentation of each 20-trial condition, the experimenter informed the subject of the variable levels involved (e.g., "large targets, in clutter, with four possible gap orientations - up, down, left, or right"), directed the subject's attention to the screen, and presented the trials, recording the response time between each trial. Between conditions, subjects were given a rest of approximately 30 seconds.

During each experimentation period room lights were extinguished. Ambient light between trials was approximately 0.1 foot candle. The screen was illuminated during trials at five candles per square foot.

Data Analysis Procedures

As data was collected, it soon became apparent that the reaction time in the initial trial in each set of twenty trials tended to be a relatively high value, higher than the average reaction time for that set of trials. Independently, one subject also observed that some visual and mental readjustment occurred in the initial trial of each set. The decision was made that in the analysis the initial value of each set of twenty trials would not be included, that is, that the average reaction time for the set would be calculated using the second through twentieth trials.

Response errors were noted on the data sheets as they occurred, however, error rates were so low (below 2% for all subjests and below 1% for most) that in the analysis information transmitted in mental processing was considered equal to input information content (information content in the stimuli). Physical errors (misstrikes), wherein the subject missed the response switch in his attempt to respond, were completely discarded as trials during data collection.

Once the data was collected, mean response times for each condition (combination of variable levels) were calculated for each subject and across subjects (see Table C-1). These were plotted against information content (see Figures D-1 through D-6 and Figure 4-1), and linear regression models were fitted to the response time-information content data. Slope coefficients and intercept values were determined for all combinations of target size and "confusion". (To provide for independence between slope and intercept, "transformed" intercept values were calculated; see Appendix B.) These regression coefficients are tabulated in Table C-2. To evaluate the data for homoscedasticity, an assumption underlying the analysis of variance, the standard deviations of the regression coefficients of the data averaged across subjects were calculated for each condition; these standard deviations are shown in Table C-3.

Although the plots of mean reaction time versus information content graphically reveal certain aspects of the data, analysis of variance was applied to the regression coefficients of the data averaged across subjects in order to evaluate the project hypothesis mathematically. The analysis of variance was performed using the "ANOVA" program available in the Statistical Package for the Social Sciences (SPSS) computer package. The ANOVA model used in this analysis is shown in Appendix B. The null hypothesis in this analysis is essentially that the dependent variable (the slope coefficient or the intercept value in this study) is not affected by the independent variables (subject, target size, or "confusion"). Support for the hypothesis of the project would be provided if the ANOVA null hypothesis were rejected when intercept values were analyzed and not rejected when slope coefficients were analyzed. This would be to say that the variables subject, target size, and "confusion" do indeed affect the intercept value but cannot be shown to affect the slope (which is the reciprocal of the information processing rate).

When ANOVA is applied to the slope coefficients, we are most interested in the possibility of not rejecting the null hypothesis and also in the degree of assurance with which we can accept that the variables analyzed do not affect the slope. This calls for the "Type II error probabilities" to be determined. (Type II error probability is the probability of accepting the null hypothesis when it, in fact, is false, given a particular type I error probability.) These values were calculated using the ANOVA residual variance as an estimate of the true variance and assuming a type I error probability of 0.05; they are shown in Table C-5.

CHAPTER IV

EXPERIMENTAL RESULTS AND CONCLUSIONS

Results

A graph of response times averaged across subjects versus average information content of stimuli is shown in Figure 4-1. Although firm conclusions cannot be made from these graphical results, some notable aspects of the graph are the good linearity of the response times for all conditions except the small target/cluttered field condition and the large difference in magnitude between the response times under the small/clutter condition and all other conditions. The graphs of response time versus information content for each individual subject are shown in Appendix D.

The analysis of variance models developed to fit the regression coefficients derived from the reaction time data are shown in Appendix B. The analyses included:

- ANOVA's on slope and intercept coefficients with all interactions with error.

- ANOVA's on slope and intercept coefficients with three-way interactions only pooled with error.

- A special ANOVA on slope coefficients where in the slope coefficient for one condition (large targets, fixed in location) under subject 4 was adjusted to account for an outlying reaction time. In this case the response time for large targets, fixed in location containing one bit

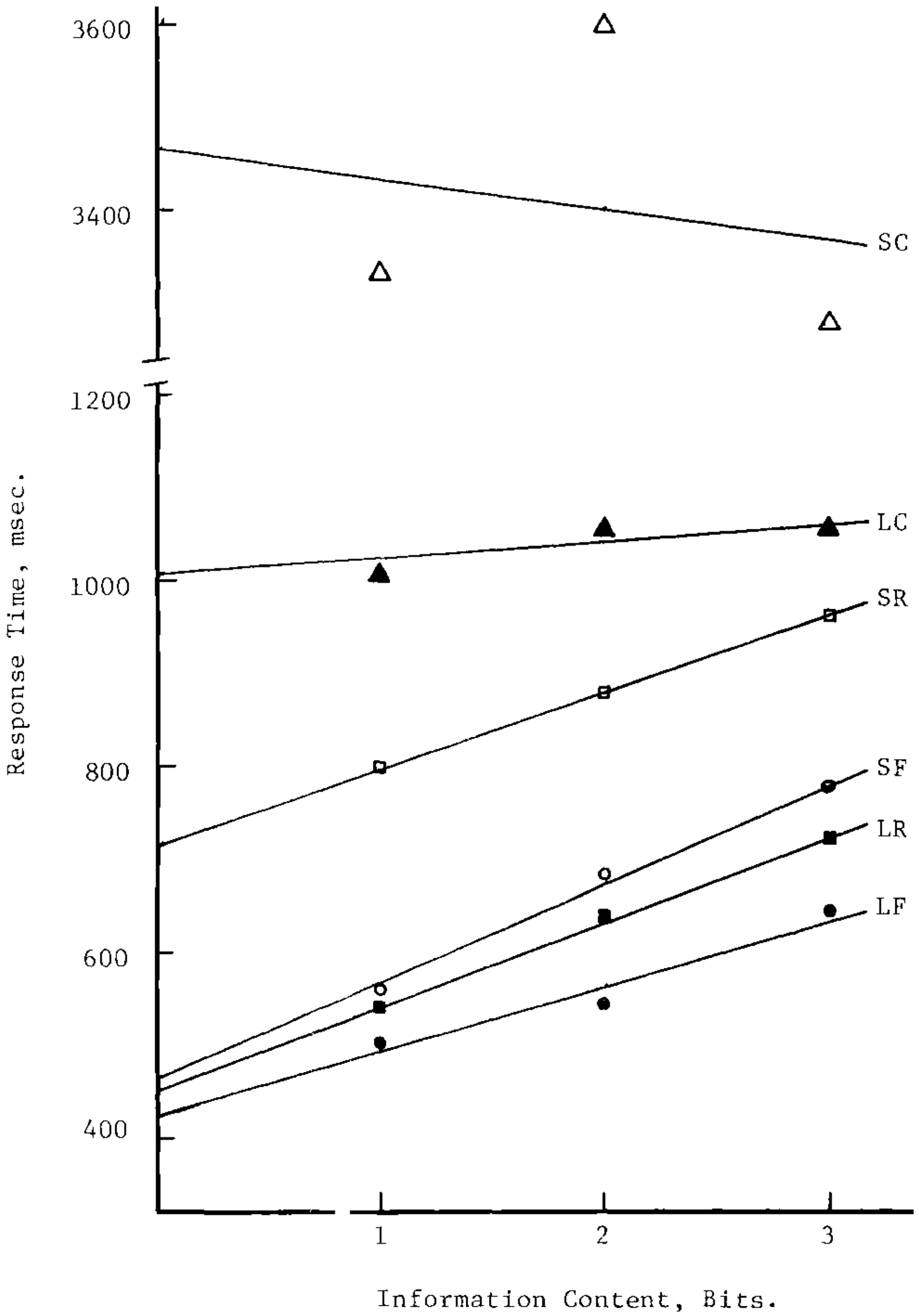

Figure 4-1. Reaction Time Averaged Across Subjects vs. Information Content.

(△ = values for small targets/cluttered field, SC. □ = small/random, SR. ○ = small/fixed, SF. ▲ = large/clutter, LC. ■ = large/random, LR. ● = large/fixed, LF.)

of information was unexpectedly high, so a slope coefficient was calculated without including that outlying value.

- ANOVA's on slope and intercept coefficients wherein the slopes and intercepts for conditions involving clutter were deleted.

ANOVA tables illustrating the main results are shown in Table 4-1, and the remaining ANOVA tables for the analyses described above are included in Appendix C (Table C-4).

Concerning the slope coefficients, ANOVA revealed that the null hypothesis for the fixed effects model, that the true slope coefficients are equal, could not be rejected at the 5% significance level for all effects in all analyses. The "degree of confusion" effect did show significance at the 7.6% level for ANOVA on slopes with only 10 degrees of freedom in the residual term (3-way interactions pooled) and at the 8.8% level for the special ANOVA with the adjusted value inserted. In all other cases, no effects were significant at 10% or less, a lenient hypothesis-rejection level. A glance at the graphs for each subject and the overall plot of reaction time versus information content shows that the slope of the line through the "small, clutter" condition shows distinct visual variation from the other lines on each graph. It is reasonable, then, that the "confusion" variable, of which clutter is one level, may show significance. This significance completely disappeared in the analysis of variance wherein the clutter level of the "confusion" variable was deleted, indicating a distinct effect of that particular variable level.

The intercept coefficients were highly affected by the target size and confusion variables in all analyses, showing significance at the 0.1% level. The subject variable was considerably less significant for this

TABLE 4-1. ANOVA Tables for Main Results.

ANOVA on Slope Coefficients - all interactions pooled with error.

Source of Variation	Sum of Squares	df	Mean Square	F	Signif.*
Subjects	55125.796	5	11025.159	0.720	0.999
Size	217.071	1	217.071	0.014	0.999
Confusion	70892.586	2	35446.298	2.316	0.116
Residual	413199.150	27	15303.672		
Total	539434.612	35			

ANOVA on Intercept Coefficients - all interactions pooled with error.

Source of Variation	Sum of Squares	df	Mean Square	F	Signif.
Subjects	1511752.545	5	302350.509	0.570	0.999
Size#	7336784.822	1	7336784.822	13.833	0.001#
Confusion#	19069863.216	2	9534931.608	17.977	0.001#
Residual	14320533.960	27	530390.147		
Total	42239834.543	35			

* Type I error probability

Type I error probability less than 0.10.

data, showing significance at less than 10% (at 8%) only in the analysis wherein clutter was deleted as a variable level.

In cases where the null hypothesis of an analysis of variance model cannot be rejected, because the probability of incorrectly rejecting the hypothesis (the type I error) is large, it is important to investigate the probability of the type II error, that is, accepting the null hypothesis where it is not true. A tabulation is provided in Table C-5 of this error probability for the ANOVA's on slope coefficients. This table lists the actual type I error probability and the type II error probabilities assuming a type I probability of .05 and using the variance of the residual error in the ANOVA as as estimator of the true variance. It can be seen that this probability is fairly high for all cases where the actual type I error probability is greater than 10%. (It may be noted that tables illustrating the type II error for a type I error probability of 0.10 were not available; such tables would yield type II error probabilities somewhat lower than those shown in Table C-5.) For comparison purposes, the minimum average value of the absolute deviation from the grand mean attributable to each variable necessary to provide a type II error probability of 0.20 was calculated, based on a type I error of 0.05, and listed in Table C-5 along with the actual average absolute deviation from the grand mean attributable to each variable. With the number of variable levels used in this study, the necessary absolute deviation to provide a type II error probability as low as 20% is considerably larger in most cases than the actual absolute deviation from the average slope. Furthermore, the magnitude of the actual average absolute deviations, from the average slope when compared to the magnitude of the average slope, indicates that a larger number of variable levels would be required to strengthen the acceptance of the null hypothesis.

An underlying assumption of the analysis of variance technique is that of homoscedasticity of the data, that is, that the variance of the dependent variable is the same at all levels of the independent variable. As can be seen from Table C-3, this is not the case, most notably for the "small, clutter" experimental condition for both the slope coefficient and the intercept value. Lack of homoscedasticity of the data tends to make the ANOVA significance levels higher than truly justified.

Some peripheral data is shown below in Table 4-2; given are error rates, error tendencies, and mean simple reaction times by subject and averaged across subjects.

TABLE 4-2. Error Rates and Simple Reaction Time

Subject No.	Error Rate	Error Tendency*	SRT msec.
1	1.5%	early	310.1
2	0.5%	late	281.1
3	0.33%	even	343.6
4	1.33%	late	349.1
5	0.17%	even	318.4
6	0.5%	even	420.1
Average	0.72%	-	337.1

* "Early" - most errors occurred early in experimental sequence.
"Late" - most errors occurred late in experimental sequence.
"Even" - errors distributed throughout sequence.

There was no consistent tendency in errors attributable to fatigue or learning.

Conclusions

The analyses of variance reported in the previous section give rise to the following conclusions:

- The transformed intercepts of the linear regression models relating reaction time to information content are definitely affected by varying target size and "degree of confusion" in such a way that the intercepts are different for different variable levels. It is not clear that intercept values are affected by different subjects.

- The slopes of those functions (the reciprocal of the information processing rate) were not shown to be different for differing levels of target size and "confusion" and for different subjects, that is, they are possibly equal. This is particularly true when the "clutter" level of the confusion" variable is deleted. The conclusion of equality of slopes (acceptance of the null hypothesis in the fixed effects ANOVA model) is not justified by the results of this study, however, since the probability of accepting a false null hypothesis runs from 51% to above 90% for various variables and various analyses.

Comparison of the results of the analyses of variance on slopes with and without clutter included as a level of "confusion", along with comparison of the graph of the "small, clutter" target condition with the graphs of the other conditions, seems to indicate that clutter in the visual field introduces a phenomenon not present in the other target conditions. Apparently the presence of clutter or distracting targets introduces, or at least markedly increases, the time necessary to locate the target. Increasing clutter <u>density</u> also seems to increase search time to the point that search time takes up the major proportion of overall reaction time. Increased clutter density seems to also greatly increase variability of overall response time. This leads to speculation that a good approximation of decision time for situations involving a cluttered visual field may be developed by relating search time only to clutter density and field size, ignoring other variables.

With respect to the objective of this study, the results lend some support to the concept presented earlier for incorporating decision time into predetermined motion-time systems. That concept, again, consists of developing a "basic detection time" from the effects of such variables as target size, target movement, temporal uncertainty, etc. and developing an additional increment of time based on average information content in the situation ("information processing time") by simply multiplying that information content by a constant. The results indicate that "basic detection time" is definitely affected by varying levels of target size, location certainty, and visual noise (clutter). There are also indications that "information processing time" can be established based on information content, independent of the other variables in this study; this cannot be a firm conclusion, however, since the probability of being incorrect in that conclusion is high. The conclusion concerning information processing time might be strengthened in a study involving a greater number of levels of the variables investigated and a greater number of subjects.

Suggestions for Future Study

An obvious extension of this study would be to investigate in detail the effect of clutter, as indicated above, on search time and on overall reaction time. Variables in such a study could include clutter density, target size-to-field size ratio, and target-to-clutter similarity.

On a larger scale, the effects of variables other than target size, clutter, and location uncertainty listed in Chapter I should be investigated in conjunction with one another, rather than predominantly independently or in small combinations as has been done in the past, in order to verify the independence of information content from the other variables and to investigate the additivity of their effects on "basic detection time".

Specific research to determine whether illumination and target-to-background contrast affect both simple reaction time and information processing time and development of a model of that effect are also needed.

Finally, once the individual and combined effects of the industrially significant variables on decision time are understood, a study involving a large number of subjects and variable levels should be completed, in order to develop detailed numerical tables usable in a predetermined motion-time system.

APPENDIX A

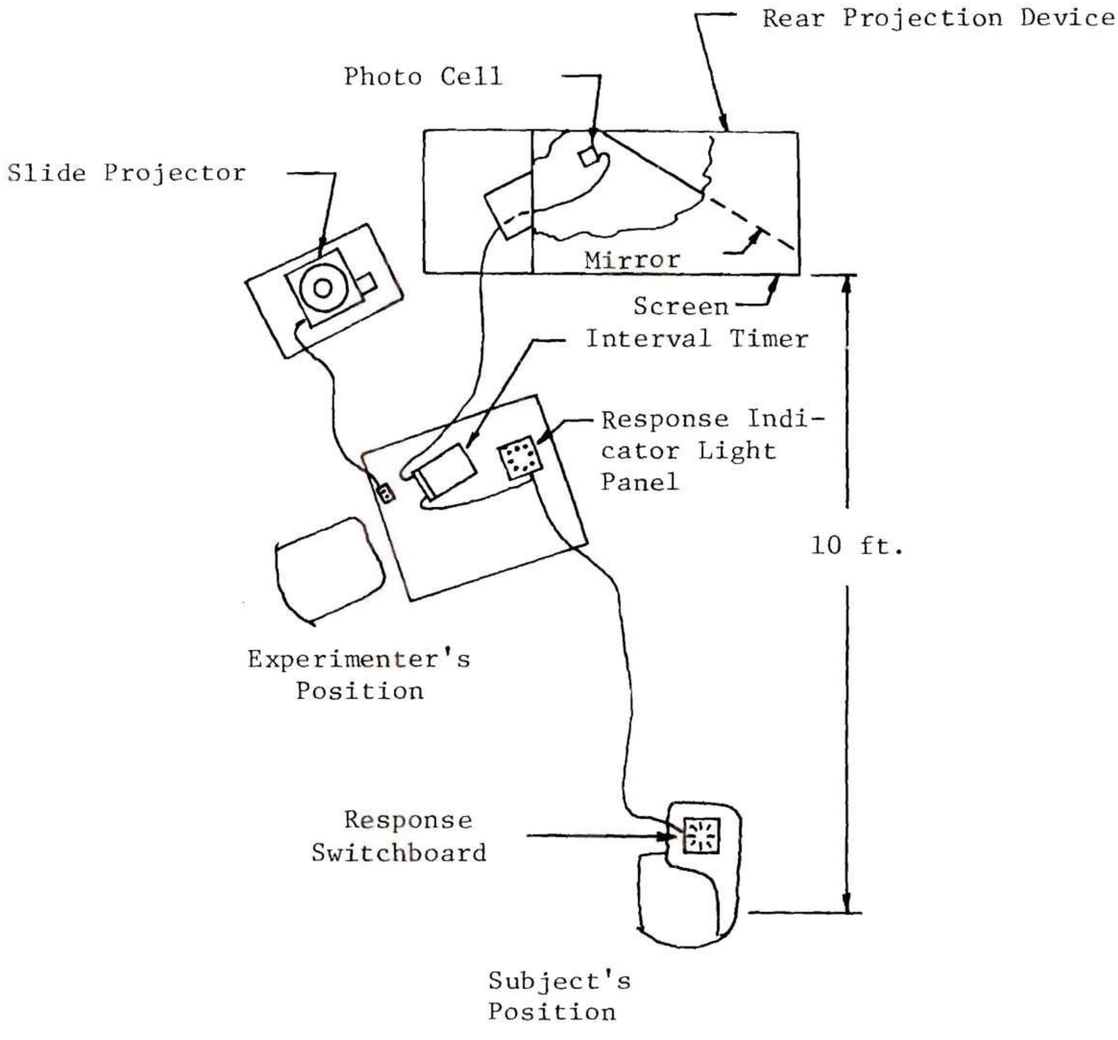

Figure A-1. Plan View Diagram of Experimental Equipment Arrangement.

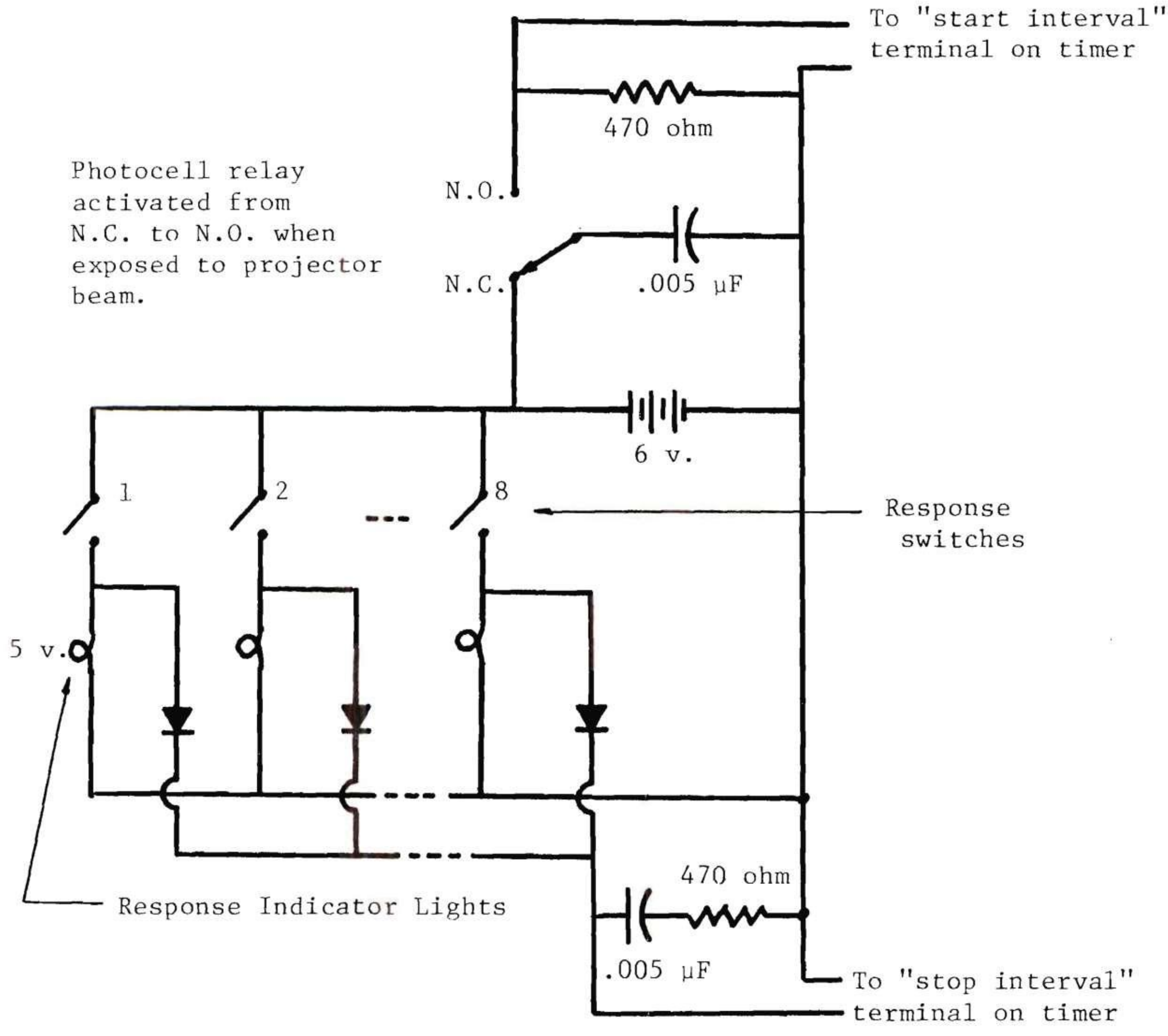

Figure A-2. Electrical Schematic Diagram of Experimental Equipment.

APPENDIX B

MATHEMATICAL MODELS

I. Linear Regression Model:

$$RT_i = a' + b\,(H_i - \bar{H}) + \varepsilon_i$$

where:

RT_i = average reaction time for condition i

a' = a constant (the transformed intercept)

b = a constant (the slope coeff.)

H_i = information content in condition i

$\bar{H}$ = average information content across all conditions

ε_i = random variation.

This is the "transformed" linear regression model that allows independence of a' and b. These coefficients are calculated, for a particular set of RT_i and H_i ($i = 1, \ldots, n$), by:

$$b = \frac{\sum_i^n RT_i\, H_i - \dfrac{\sum_i^n H_i \sum_i^n RT_i}{n}}{\sum_i^n (H_i^{\,2}) - \dfrac{(\sum_i^n H_i)^2}{n}}$$

and

$$a' = \frac{\sum_i^n RT_i}{n}$$

II. Analysis of Variance (ANOVA) Models.

For ANOVA fitted to slope coefficients:

$$b_{ijk} = \mu_b + S_{bi} + Z_{bj} + C_{bk} + S_{bi} Z_{bj} + S_{bi} C_{bk}$$

$$+ Z_{bj} C_{bk} + S_{bi} Z_{bj} C_{bk} + \varepsilon_b{}^i{}_j{}^k$$

where:

b_{ijk} = value of the slope coefficient for a particular set of conditions i, j, and k.

μ_b = the long run average slope.

S_{bi} = term to account for the effect of subject i.

Z_{bj} = term to account for the effect of target size j.

C_{bk} = term to account for the effect of degree of confusion k.

$S_{bi}\ Z_{bj}$, etc. = terms to account for interaction between variable levels.

$\varepsilon_b{}^k{}_j{}^k$ = random variation of b occurring in condition i, j, k.

A similar model is developed using equivalent terms for intercepts a'. For a detailed discussion of the Analysis of Variance technique and rationale see Hicks, Charles R., <u>Fundamental Concepts in the Design of Experiments</u>.

APPENDIX C

TABLE C-1. Mean Reaction Times.

Condition	Subjects						
	1	2	3	4	5	6	$\overline{\overline{RT}}$**
1 LF*	472.5	448.7	445.4	660.0	504.3	485.5	503.7
2 LF	481.0	500.4	466.0	570.3	605.8	652.1	545.9
3 LF	522.2	604.2	595.5	739.1	692.1	694.6	641.3
1 LR	536.6	566.5	523.9	523.4	533.0	558.1	540.3
2 LR	652.5	574.1	575.0	637.8	599.4	798.5	639.6
3 LR	605.8	662.2	649.6	787.7	768.2	841.4	719.2
1 LC	895.9	1052.7	1030.4	985.6	898.5	1250.8	1019.0
2 LC	907.3	1046.8	1098.5	1041.1	934.9	1318.2	1057.8
3 LC	986.7	1016.6	1066.3	1112.7	930.9	1203.8	1052.8
1 SF	565.0	504.0	508.8	573.3	571.2	632.7	559.2
2 SF	645.9	665.0	647.3	561.3	737.8	734.2	681.8
3 SF	779.1	806.7	746.9	708.6	785.1	837.4	777.3
1 SR	643.0	727.5	868.6	891.1	881.9	770.8	797.2
2 SR	780.1	783.4	852.8	1063.0	822.3	963.6	877.5
3 SR	810.7	922.9	1064.1	971.4	967.6	1027.2	960.7
1 SC	2384.8	2625.0	3261.3	3101.8	2987.8	5657.6	3336.4
2 SC	2386.2	2939.9	4721.8	3080.4	2607.5	5830.8	3594.4
3 SC	2750.2	2694.2	3922.1	3063.4	2522.3	4692.3	3274.1
SRT	310.1	281.1	343.6	349.1	318.4	420.1	337.1

* Variable levels indicated: Info. content - 1, 2, or 3 bits; target size - Large or Small; Degree of Confusion - Fixed, Random, or Clutter.

** $\overline{\overline{RT}}$ - Reaction times averaged across subjects.

TABLE C-2. Linear Regression Coefficients: Slopes and Transformed Intercepts

Slope Coefficients
(msec./bit)

Condition	Subjects 1	2	3	4	5	6	Across Subjects
LF*	24.9	77.8	75.0	36.6	93.9	104.6	68.8
				(168.8)**			
LF	34.6	47.9	62.9	132.2	112.6	141.7	89.5
LC	45.4	-18.1	18.0	63.6	16.2	-23.5	17.4
SF	107.0	151.4	119.1	67.2	106.3	102.4	104.1
SR	83.9	97.9	97.8	40.2	42.9	128.2	81.7
SC	183.4	34.6	330.4	-19.2	-232.8	-482.6	-31.2

Transformed Intercepts
(msec.)

Condition	Subjects 1	2	3	4	5	6	Across Subjects
LF	491.9	517.8	402.3	658.5	600.7	610.7	563.6
				(570.3)**			
LR	598.2	600.9	582.8	649.6	630.2	732.7	633.0
LC	930.0	1038.7	1065.1	1046.5	921.4	1257.6	1043.2
SF	663.3	658.6	634.3	614.4	698.0	737.8	672.8
SR	744.6	811.3	928.5	975.2	880.6	920.5	878.5
SC	2506.6	2753.0	3968.4	3081.9	2725.9	5393.6	3401.6

* Variable levels as in Table C-1.

** Values determined by omitting the mean reaction time for condition 1 LF, which seemed excessively high.

TABLE C-3. Standard Deviations of Regression Coefficients by Condition.

Condition	Slope, b	Std. dev., S_b	Intercept, a'	Std. dev., S_a
LF	68.8	8.1	563.6	6.6
LR	89.5	9.2	633.0	6.7
LC	17.4	17.3	1043.2	14.1
SF	104.1	7.7	672.8	6.3
SR	81.7	13.2	878.5	10.8
SC	-31.2	95.8	3401.6	78.2

TABLE C-4. ANOVA Tables

1. ANOVA on Slope Coefficients - 3-Way Interactions Pooled with Error

Source of Variation	Sum of Squares	df	Mean Square	F	Significance
Subjects	55125.749	5	11025.159	1.042	0.445
Size	217.021	1	217.071	0.021	0.999
Confusion#	70892.596	2	35446.298	3.350	0.076#
Subject-Size	99254.579	5	19850.916	1.876	0.186
Subject-Confus	196478.861	10	19647.886	1.857	0.172
Size-Confus	11650.816	2	5825.408	.551	0.999
Residual	105814.894	10	10581.489		
Total	539434.612	35			

#Type I error probability less than 0.10.

*Type I error probability

2. Special ANOVA on Slope Coefficients with Adjusted Value Entered for LF Condition, Subject 4

Source of Variation	Sum of Squares	df	Mean Square	F	Significance
Subject	56961.172	5	11392.234	0.746	0.999
Size	1351.788	1	1351.788	0.088	0.999
Confusion#	80635.736	2	40317.868	2.639	0.088#
Residual	412434.593	27	15275.355		
Total	551383.289	35			

3. ANOVA on Intercepts - 3-way Interactions Pooled with Error

Source of Variation	Sum of Squares	df	Mean Square	F	Signif.
Subject	1511752.545	5	302350.509	1.840	.192
Size#	7336784.822	1	7336784.822	44.641	.001#
Confusion#	19069863.216	2	9534931.608	58.016	.001#
Subject-Size	831836.989	5	166367.398	1.012	.460
Subject-Confus	2239852.868	10	223985.287	1.363	.316
Size-Confus	9605336.640	2	4802668.320	29.222	.001#
Residual	1643507.463	10	164350.746		
Total	42238934.543	35			

4. ANOVA on Slope Coefficients with "Large, Clutter" and "Small, Clutter" Conditions Deleted

Source of Variation	Sum of Squares	df	Mean Square	F	Signif.
Subject	8029.968	5	1605.994	1.259	.329
Size	1656.682	1	1656.682	1.298	.271
Confusion	79.207	1	79.207	0.062	.806
Residual	20415.256	16	1275.954		
Total	30181.113	23			

5. ANOVA on Intercepts with "Large, Clutter" and "Small, Clutter" Conditions Deleted

Source of Variation	Sum of Squares	df	Mean Square	F	Signif.
Subject#	48375.093	5	9675.019	2.434	0.080#
Size#	180578.802	1	180578.802	45.429	0.001#
Confusion	114512.535	1	114512.535	28.809	0.001#
Residual	63598.903	16	3974.931		
Total	407065.333	23			

TABLE C-5. Type II Error Probabilities

1. Considering ANOVA on Slopes with all Interactions Pooled with Error.

Variable	Type I Error Prob.	Type II* Error Prob.	AADN**	AAAD***
Subject	.999	0.75	79.79	31.76
Size	.999	0.9+	54.07	2.46
Confusion	.116	0.51	62.36	41.81

2. Considering ANOVA on Slopes with Clutter Conditions Deleted

Variable	Type Error Prob.	Type II Error Prob.	AADN	AAAD
Subject	.40	0.60	27.9	14.1
Size	.40	0.75	19.4	9.31
Confusion	0.999	0.9+	19.4	1.82

*Calculated assuming a type I error probability of 0.05 and standard deviation of residual taken as true standard deviation.

**Minimum average absolute deviation within the variable necessary to establish a type II error probability of 0.20, given the number of variable levels used.

***Actual average absolute deviation from the grand mean within the variable.

Grand mean slope = 55.67.

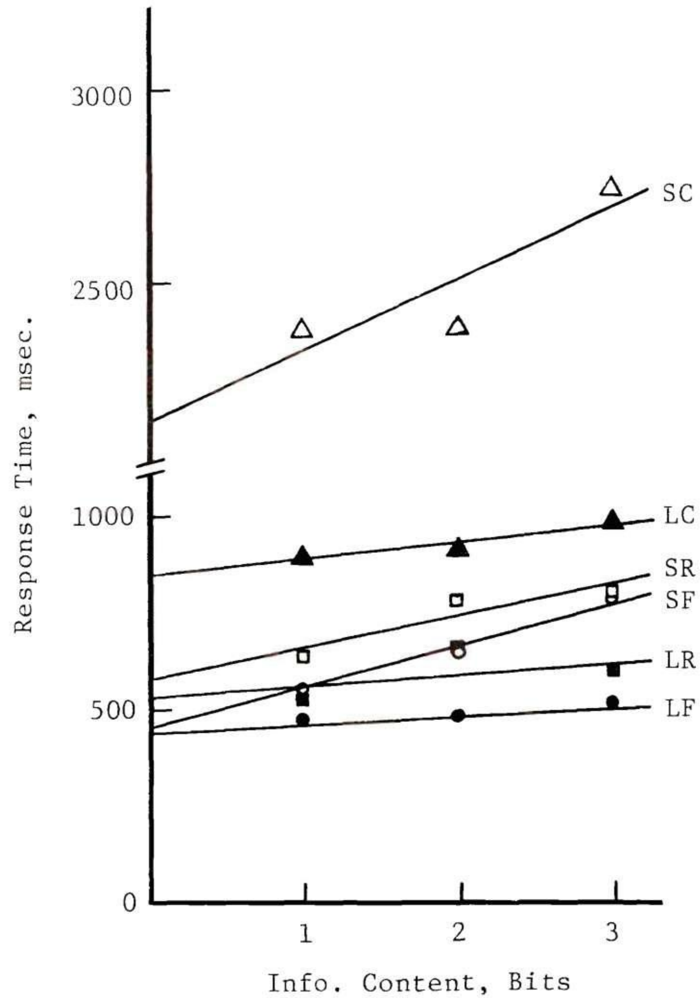

Figure D-1. Mean RT vs. Information Content - Subject 1.

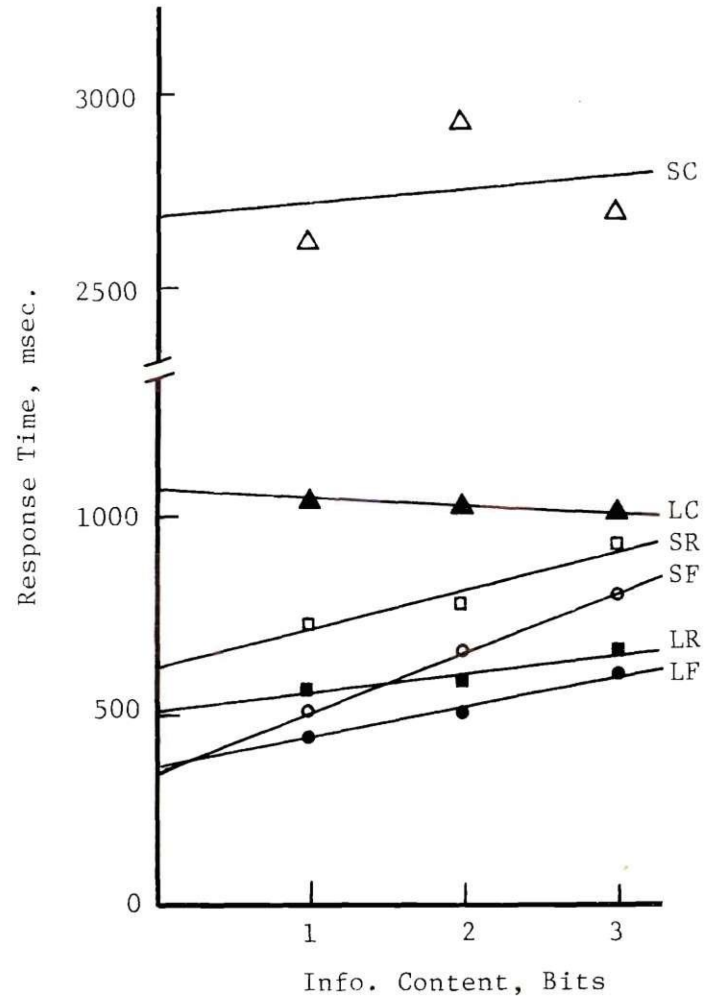

Figure D-2. Mean RT vs. Information Content - Subject 2.

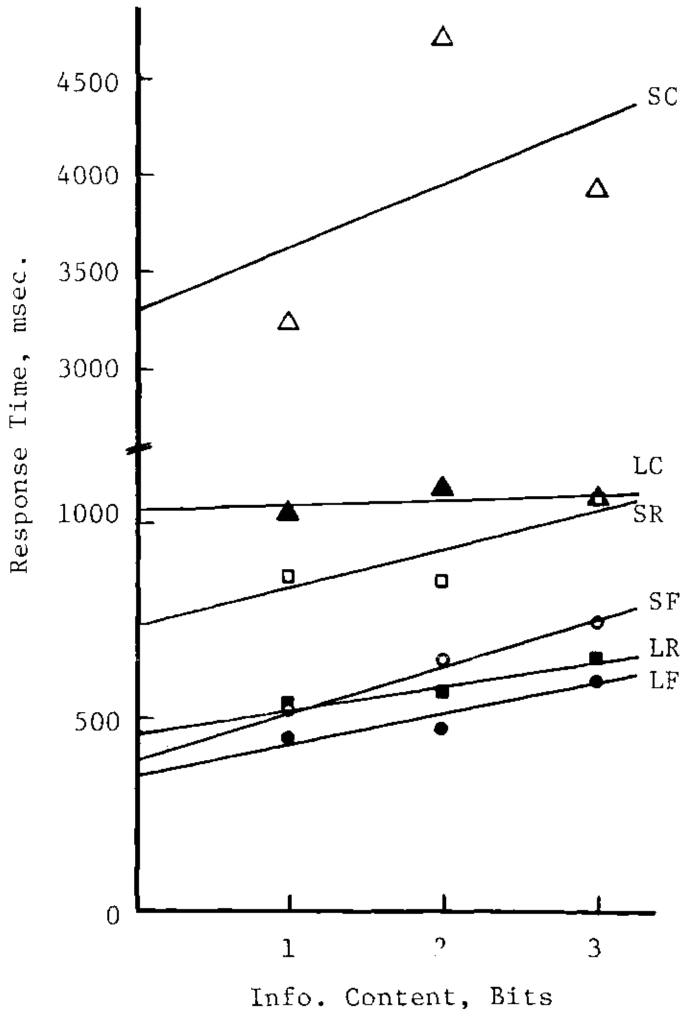

Figure D-3. Mean RT vs. Info. Content-
Subject 3.

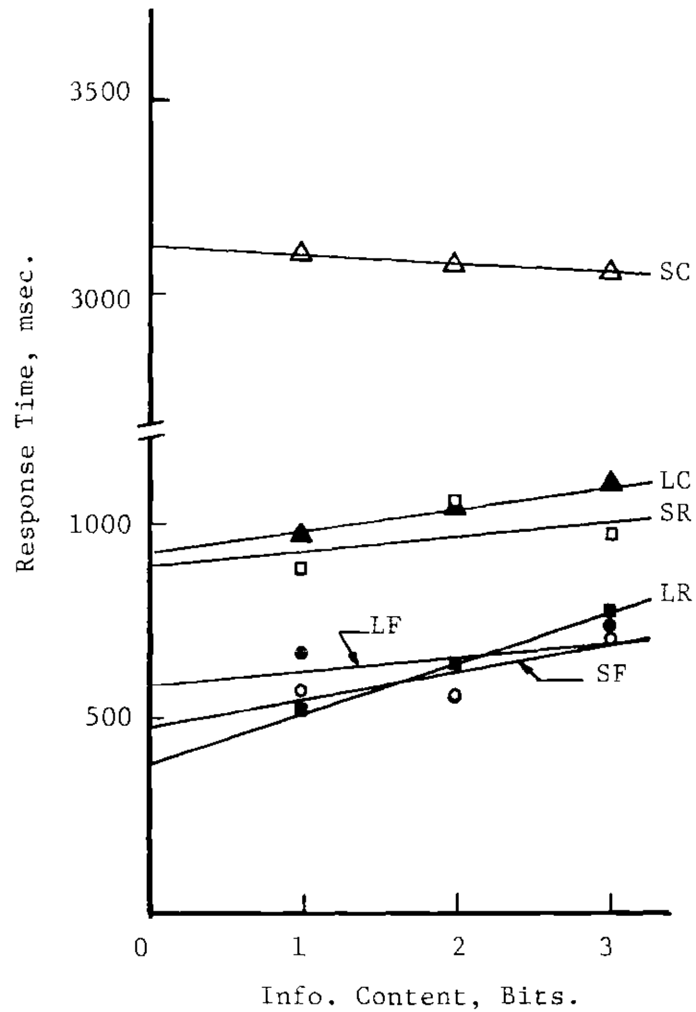

Figure D-4. Mean RT vs. Info. Content-
Subject 4.

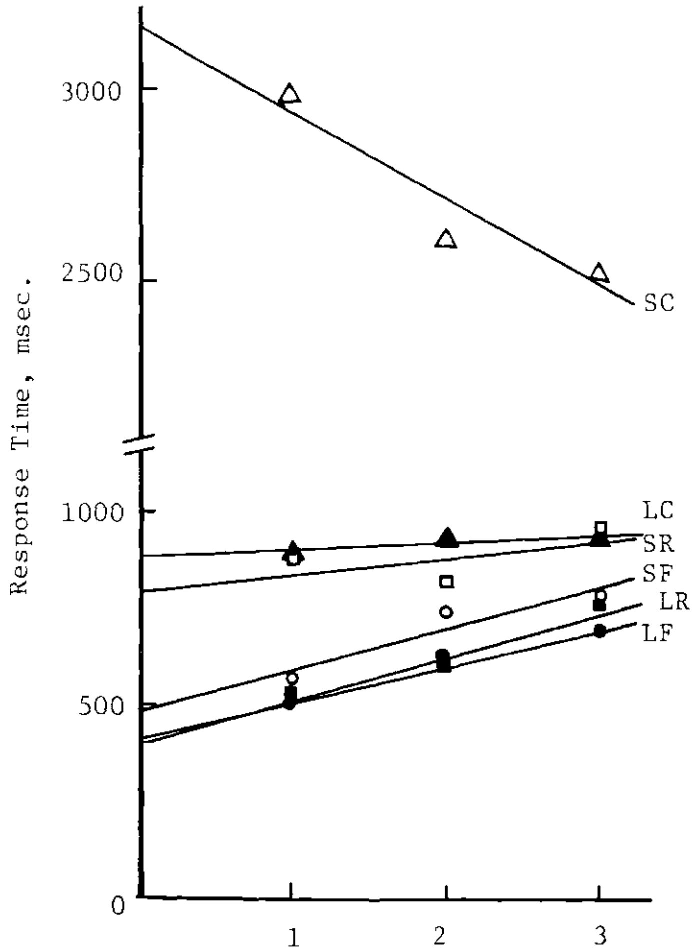

Figure D-5. Mean RT vs. Info. Content - Subject 5.

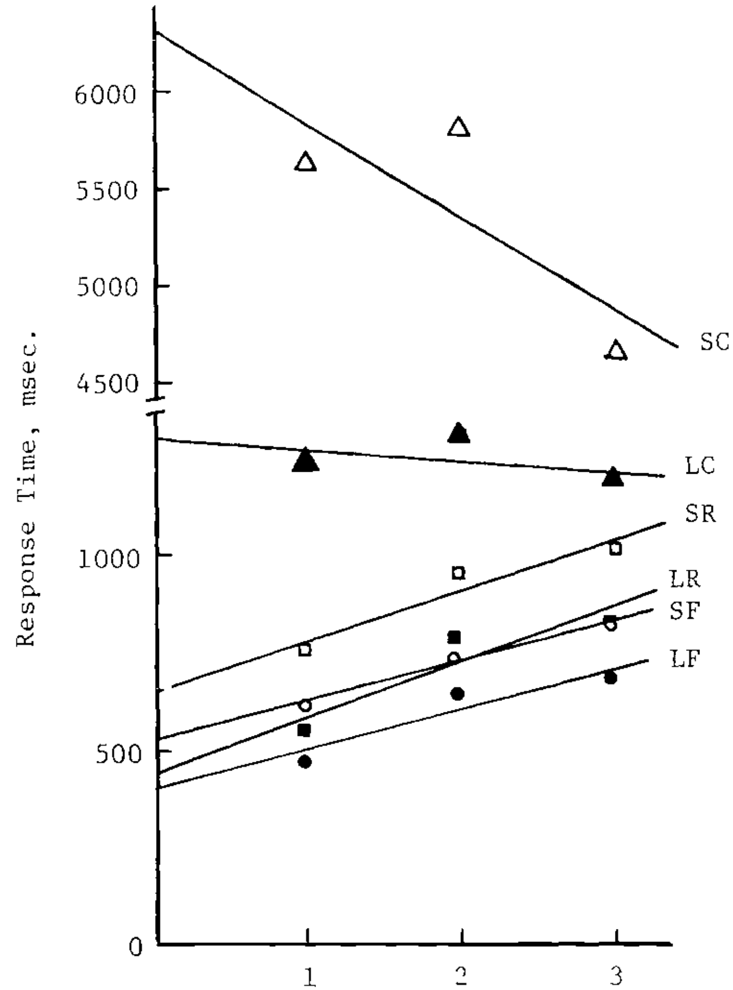

Figure D-6. Mean RT vs. Info. Content- Subject 6.

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